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POLLUTION OF THE INTERSTATE WATERS OF THE COLORADO RIVER AND ITS TRIBUTARIES. COLORADO, NEW MEXICO, ARIZONA, CALIFORNIA, NEVADA, WYOMING AND UTAH. PROCEEDINGS OF CONFERENCE, SEVENTH SESSION, HELD AT LAS VEGAS, NEVADA ON FEBRUARY 15-17, 1972

Environmental Protection Agency
Washington, D. C.

1972

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SEVENTH SESSION
OF THE
CONFERENCE
IN THE MATTER OF
POLLUTION OF THE INTERSTATE WATERS
OF THE COLORADO RIVER AND ITS TRIBUTARIES -
COLORADO, NEW MEXICO, ARIZONA, CALIFORNIA,
NEVADA, WYOMING AND UTAH

held at

Las Vegas, Nevada

February 15-17, 1972

TRANSCRIPT OF PROCEEDINGS

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The Seventh Session of the Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and its Tributaries - Colorado, New Mexico, Arizona, California, Nevada, Wyoming and Utah, convened at 9:30 o'clock on February 15, 1972, in the Las Vegas Convention Center, 3150 South Paradise Road, Las Vegas, Nevada.

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George Jones, Las Vegas	Review Journal

George Smith, Arizona Republic
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Court Reporter

MORNING SESSION

TUESDAY, FEBRUARY 15, 1972

9:30 o'clock

OPENING STATEMENT

BY

MR. MURRAY STEIN

MR. STEIN: Will the conferees take their places, please.

The conference is open.

This seventh session of the Conference in the Matter of Pollution of the Interstate Waters of the Colorado River in the States of California, Colorado, Utah, Arizona, Nevada, New Mexico, and Wyoming is being held under the provisions of Section 10 of the Federal Water Pollution Control Act, as amended. Under the provisions of the Act, the Administrator of the Environmental Protection Agency is authorized to initiate a conference of this type when on the basis of reports, surveys, or studies he has reason to believe that pollution subject to abatement under the Federal Act is occurring.

The first session of the Colorado River enforcement conference was held in January 1960, and was initiated on written requests from the State water pollution control agencies of New Mexico, Arizona, Colorado, California, Nevada, and Utah, with Wyoming concurring. Six previous sessions have been held beginning in 1960, and several aspects of pollution in the Colorado River Basin have been considered and remedial programs established.

As specified in Section 10 of the Act, the official State and interstate water pollution control agencies have been notified of this conference by Administrator Ruckelshaus. These agencies are the California Water Resources Control Board; the Colorado Department of Public Health; the Nevada Commission of Environmental Protection; the New Mexico Environmental Improvement Agency; the Utah Department of Social Services; the Wyoming Division of Health and Medical Services; and the Arizona Department of Health.

Both the State and Federal Governments have responsibilities in dealing with water pollution control problems. The Federal Water Pollution Control Act declares that the States have primary rights and responsibilities for taking action to abate and control water pollution. Consistent with this, we are charged by law to encourage the States in these activities.

At the same time, the Administrator of the Environmental Protection Agency is charged by law with specific responsibilities in the field of water pollution control in connection with pollution of interstate and navigable waters. The Federal Water Pollution Control Act provides that pollution of interstate or navigable waters which endangers the health or welfare of any persons shall be subject to abatement. This applies whether the matter causing or contributing to the pollution is discharged directly into such waters or reaches such waters after discharge into a tributary.

The purpose of this conference is to discuss, among other things, the pollution problems associated with the salinity content of the Colorado River and the control and disposition of uranium mill tailings piles.

Several of you may have forgotten, as I think I have reminded you, that at the beginning we were invited in here by the overwhelming majority of the States in this basin. The reason for this invitation was because of the crucial problem we were facing in water pollution in this river at the time, and that was the problem of radioactive pollutants getting inte the river.

I think given the nature of the problem, the number of States involved, seven States, and the record, this is certainly a case where we can point with pride to the control of radioactive wastes in the river. An effective program had been set up and after repeated meetings and conferences we did secure the cooperation of the uranium milling industry, the AEC, and launched upon a cleanup program. At the last reports, at least when I looked at this, the radium content was about one-third that of Public Health Service drinking water standards and really approaching background levels. We still may have the problem in the disposition of the tailings.

We also had when we started this program and recognized it a very, very difficult problem of salinity. In addition to the question of the usual municipal and industrial waste discharges into rivers, there was a very special problem in the Colorado River. We have extensively studied this. This has proved to be one of the most difficult problems of pollution control that we have had in the country. I think possibly you can apply a rule to this business that when you can come down to a point source, or even in an industry get down to a specialized stream, you can control something much better than you can when the source is spread over a tremendous area and is ubiquitous.

Art Williamson called something to my attention this morning. I hope it won't be, but it seems that the pollution problem may be longer enduring than the conferees, since Art Williamson, myself, and Lynn Thatcher from Utah, who I hope will be here soon, are the only three who were here at the beginning. The others are all new--not new but they have changed. But the problem is still with us.

So the problem is still with us, and the recognition that we have and must have in dealing with a problem like this is, unless we deal with all parties concerned, we probably are not going to make too much progress in meeting the problem. I think the problem has been analyzed. But I think also that the solution of the problem is going to take all the help we can get, and I am not sure that any problem like this can be solved by disputes over State, Federal rights, international rights, etc. We have a very tough physical pollution problem and water quality problem to be dealt with, and we just have to put our minds to training to do that.

I would like the conferees to introduce themselves, and I wonder if we could start on the left.

Art.

MR. WILLIAMSON: Art Williamson, State of Wyoming.

MR. SLINGERLAND: Carl Slingerland, State of New Mexico.

MR. O'CONNELL: Richard O'Connell with the Environmental Protection Agency, San Francisco.

MR. DICKSTEIN: Irwin Dickstein, Environmental Protection Agency, Region VIII, Denver.

MR. WESTERGARD: Roland Westergard, State of Nevada.

MR. ROZICH: Frank Rozich, State of Colorado.

MR. DIBBLE: E. F. Dibble, State of California.

MR. TABOR: C. C. Tabor, State of Arizona.

MR. STEIN: My name is Murray Stein and I am from EPA in Washington and the representative of Administrator William Ruckelshaus.

Now a word about the conference.

The parties to the conference are the official State water pollution control agencies whom you have just heard and the Utah agency and the Environmental Protection Agency. Participation in the conference will be open to representatives and invitees of these agencies and such persons as inform me that they wish to make statements. However, only the representatives of the official agencies constitute the conferees.

Now a word about the procedures governing the conduct of the conference. The conferees will be called upon to make statements and in addition the conferees may call upon participants whom they have invited to make a statement. We shall call on other individuals who wish to make statements after that who have indicated that they would like to make a statement.

At the conclusion of each statement, the conferees will be given an opportunity to comment or ask questions, and I may ask a question or two. This procedure has proven effective in the past in reaching equitable solutions.

Although we cannot entertain questions or comments from the floor, you may be assured that everyone will have an opportunity to be heard fully. Please save your comments and questions and you will be given an opportunity to make these points when your turn comes to speak.

At the end of all the statements, we will have a discussion among the conferees and try to arrive at a basis of agreement on the facts of the situation. Then we will attempt to summarize the conference, giving the conferees, of course, the right to amend or modify the summary.

I should indicate that at the end of the conference, the Environmental Protection Administrator is required to make recommendations for remedial action if such recommendations are indicated.

A verbatim transcript and record of the conference is made by Virginia Rankin for the purpose of aiding us in preparing a summary and also providing a complete record of what is said here. It usually takes about 3 or 4 months for the transcript to come out in printed form. If you wish a record or part of it beforehand, you can check with the reporter, who is under contract, and make your own arrangements with Mrs. Rankin.

I would also indicate that we do not print in color, so take that into account with any charts or visual aids you may present. They will be in black and white. Try not to refer to color if you use graphic aids in your presentation as they will be meaningless in the reading of the transcript or making of the transcript.

We will make copies of the transcript available to the official State water pollution control agencies, along with the summary. If you wish, at the conclusion of the conference, you can ask them for copies of the transcript and the summary of the conference.

Roughly we will take up in the order of procedure the tailings question and then the salinity question. But before we do so, I would like to just introduce John E. Ryan--would you stand up--of the EPA Office of Congressional and Liaison Affairs. Mr. Ryan is here. I know there has been considerable congressional interest in this. If there are any congressional representatives who have a question or want to follow through on anything, the initial point of contact should be Mr. Ryan.

We also have Joe Friedkin, United States Commissioner of the International Boundary and Water Commission.

Mr. Friedkin.

MR. FRIEDKIN: Thank you, Mr. Stein.

MR. STEIN: Nice to see you.

And Charles Cook of the Minority Council of the

Senate Interior Committee is also here. Mr. Cook.

Thank you.

Now, again, you have to recognize we have had many, many sessions of the conference before, and for the people in the audience, it may seem in dealing with some of these problems we are getting into them somewhere in the middle. We surely are. I hope we have made progress on them. But I think if you will just wait and listen to the presentations, the problems will unfold.

I would suggest, at least for the Federal people in opening this, for the sake of perspective maybe they can take a minute or two as we enter each problem to indicate what the problem is and what we are doing, not just for purposes of the record, but so the people here will be able to follow this better.

First on the tailings we would like to call on Mr. Dickstein.

Mr. Dickstein.

IRWIN L. DICKSTEIN, DIRECTOR
ENFORCEMENT DIVISION, REGION VIII
U. S. ENVIRONMENTAL PROTECTION AGENCY
DENVER, COLORADO

MR. DICKSTEIN: Thank you, Mr. Chairman.

As the Chairman mentioned earlier, the water radiological problems are in essence solved. The radioactivity of the Colorado River is not a major problem at the present time. However, there is a problem with the stabilization of mine tailings and this is what we are addressing ourselves to at this particular conference.

In the sixth session of the conference one of the recommendations was that the EPA and the AEC, actually the FWQA at that time, establish or draft a model tailings pile regulation which could be adopted by the various States that do have this particular problem, and we are addressing ourselves to this model regulation.

First of all I would like to introduce Mr. Paul Smith of Region VIII, who was the Chairman of the Tailings Pile Regulation Committee.

Paul.

MR. STEIN: I should indicate, everyone other than a panel member should come to the lectern in making his statement, and please identify yourself by full name and title for purposes of the record.

PAUL B. SMITH

U. S. ENVIRONMENTAL PROTECTION AGENCY

REGION VIII, DENVER, COLORADO

MR. SMITH: My name is Paul B. Smith and I am with the Environmental Protection Agency Region VIII office in Denver. And my statement follows.

As a result of the sixth session conference concerning pollution of the interstate waters of the Colorado River and its tributaries, an agreement was reached whereby the staffs of the Federal Water Pollution Control Administration, the Public Health Service, and the Atomic Energy Commission would assist States by providing advice and assistance regarding the development of uranium mill tailings pile stabilization and containment objectives and measures for achieving them. In this regard, I am submitting for consideration by the conferees of this seventh conference a model regulation proposal requiring stabilization of mineral mill tailings piles containing radioactive materials. This draft regulation has been developed by the EPA's Region VIII office for eventual adoption by all involved States in the country. In the development process, however, the fact that four of Region VIII's States have within their boundaries 10 of the Nation's 15 active uranium mills and 14 of the Nation's 20 inactive mill sites was a major consideration. Also significant is the fact that out of a total of 10 newly planned uranium mills which are expected to become operational over the next decade, six are to be located in Region VIII States.

The problems caused by unregulated tailings piles in Colorado and Wyoming demonstrate the need for having each uranium milling State adopt regulations requiring stabilization and control of inactive uranium mill tailings piles. Before Colorado adopted regulations on January 26, 1967, the American Metal Climax Mill in Grand Junction allowed approximately a quarter of a million tons of their tailings to be hauled away by local building contractors for various uses, which included construction fill under or around habitable buildings.

Another example of a different aspect of the uranium mill tailings control problem is the Susquehanna Western Company's abandoned mill site near Riverton, Wyoming. Here we have a monumental environmental insult to the community of Riverton and its surrounding countryside. Susquehanna's tailings pile was abandoned and left uncovered and poorly fenced and poorly marked with cautionary signs. Wind and rain have taken their toll as evidenced by widespread erosion of tailings to private lands around the old mill site. Pictorial evidence collected only recently even indicates that dump truck quantities of tailings have been removed from the Susquehanna pile by unknown persons for unknown purposes.

Within the Colorado River Basin, only the State of Colorado has regulations in force which govern the stabilization and control of radioactive mill tailings. Later during this conference, Mr. P. W. Jacoe of the Colorado delegation attending this conference, will briefly describe the usefulness of his State's regulations in managing radioactive mill tailings in Colorado. Among the conferee States in this conference, the need for Nevada and California to adopt regulations on the radioactive tailings control problem is remote since the ore milling industry in these States until now has not processed radioactive ore.

The need for adoption of a form of the proposed regulation is most critical in the States of New Mexico, Arizona, Utah, and Wyoming, since these States can anticipate having to administrate the long-range control programs dealing with radioactive mill tailings piles. In addition, the possibility of revitalizing the uranium mining and milling industry to answer this country's future energy needs must be considered a viable alternative, given the current rate in depletion of our national energy resources.

In order to visualize the magnitude of the tailings piles generated by uranium producers, consider that only about 5 pounds of uranium and 100 pounds of vanadium are removed from each ton of ore processed. The balance of 1,895 pounds of residue sands is heaped on a tailings pile as waste. At the end of 1971, this total accumulation of tailings in the United States amounts to well over 100 million tons.

Various studies have indicated that these wastes contain between 100 and 900 picocuries of radium-226 per gram of dry tailings. Using a very conservative average, concentration of 250 picocuries of radium per gram, a hundred million tons would contain about 22,000 curies of radium-226. I am sure everyone here will agree that this represents a significant potential source of unnecessary radiation exposure for a multitude of generations to come considering the fact that radium-226 has a half life of 1,620 years.

With this thought in mind, I would now like to present to the conferees the Environmental Protection Agency's model regulations requiring stabilization of mineral mill tailings piles containing radioactive materials with the recommendation that the model tailings pile regulation be adopted and implemented by the Colorado River Basin States no later than July 1, 1973.

In closing, I would like to note that we recognize Colorado's pioneering effort in regulating the stabilization of tailings piles. The proposed model regulations are based on those adopted by Colorado in 1967. We hope that these model regulations have benefited from Colorado's enforcement experiences over the last 5 years and provide the basis for improved control of radioactive tailings in all concerned States.

Thank you.

MR. STEIN: Thank you.

Without objection, I am going to have the proposed regulation entered in the record at this point as if read.

(The above-mentioned regulation follows:)

NOTICE

Publication of Regulation Adopted by
(Appropriate State Regulatory Agency)

In compliance with the provisions of Section ______, State Statutes ______, publication is hereby made of the attached Regulation adopted by the (Appropriate State Regulatory Agency) at its regular meeting of ________________________________, after due notice of the hearing thereon was published as provided by law. Said Regulation was adopted pursuant to authority contained in Section ______, Chapter ______, State Session Laws of 19___, and Sections ______ and ______, State Statutes ____________, and is captioned as follows:

"RADIATION REGULATION NO. ______ REQUIRING
STABILIZATION OF MINERAL MILL TAILINGS
PILES CONTAINING RADIOACTIVE MATERIALS."

The effective date of the said Regulation shall be __________________.

Draft Regulation Prepared by EPA, Region VIII, Denver, Colorado
1-19-71, 1-27-71, 3-30-71, 1-7-72, 1-13-72

DEFINITIONS

Tailings Pile. In the context of this Regulation, reference to any man-made surficial deposit of soil or rock which is or has been deposited as a result of milling for minerals and which contains radioactive material in concentrations exceeding that specified by the (Appropriate State Regulatory Agency) either as a specific radioactive isotope and/or as total radioactivity. (Note: Stabilization of tailings piles or material containing no concentrations of radioactive material above background levels at the site is governed by "Solid Waste Regulation No.___________" approved by the (Appropriate State Regulatory Agency).)

Stabilization. Encompasses all measures necessary to insure immediate and future protection of the environment and to eliminate hazards to health or welfare with a minimum of future maintenance. In no case shall the stabilized pile exceed or cause to be exceeded applicable health or other environmental standards.

Riprap. Broken rock, concrete, special forms of durable material, or other objects which are of sufficient size, density, hardness, and of the appropriate configuration to resist erosion, provide a surface in keeping with approved land-use patterns, and, when placed on tailings piles, retain the tailings material in place.

Erosion. All physical and chemical processes whereby the tailings material is loosened, or dissolved, and removed from any part of the tailings pile. Includes processes of weathering, solution, corrosion, and transportation. Mechanical wear and transportation are affected by running water, waves, moving ice, or winds.

Ground Water. In the context of this Regulation, reference to water beneath the land surface, in both the saturated zone and that zone where voids are filled with air and water, or the unsaturated zone, as separate from "Surface Water".

Active Tailings Pile. A Pile either (1) currently receiving material, or (2) currently within the boundaries of an active or operating mill.

> An "Active Tailings Pile" will remain in an "active" classification until the owner or assignees request in writing reclassification as an inactive pile from the Atomic Energy Commission or the (Appropriate State Regulatory Agency).

Inactive Tailings Pile. A Pile to which material is not added and which no longer resides within the site boundaries of an active mineral mill.

DEFINITIONS (continued)

Site Boundaries. The boundary between the unrestricted and restricted portions of the mill area, as defined by the appropriate State or Federal Regulation governing the possession, handling, production, or use of radioactive materials at the mill; normally the contiguous perimeter of the mill and tailings where ingress by the general public is excluded. If not elsewhere defined, the site boundaries will be interpreted as at least, but not limited to, the limits of the tailings area.

Owner. The organization, corporation, partnership, natural person, or group of persons possessing title to the property on which the tailings material is being or has been deposited, or the organization, corporation, partnership, natural person, or group of persons enjoying possession or custody of the tailings material.

Appropriate State Regulatory Agency. For the purposes of this Regulation, this means the agency, board, department, commission, or other State entity that has the authority and responsibility for tailings pile control.

INTENT

This Regulation is intended to apply only to tailings piles defined as "Inactive" by this Regulation.

Further, it is the intent of the (Appropriate State Regulatory Agency) that, while all inactive tailings piles containing radioactive materials in (state) are subject to this Regulation on the date promulgated, this Regulation in no way relieves the Atomic Energy Commission or other affected Federal Agencies of their responsibilities and jurisdiction incurred in the establishment and control of said tailings piles prior to the adoption of this Regulation.

REGULATION

1. The Owner or assignees (as defined supra) of each tailings pile is responsible for stabilization of the pile.

2. In the case of tailings piles which are in an inactive status on the effective date of this Regulation, the (Appropriate State Regulatory Agency) will determine, within a six-month period after the effective date of this Regulation, whether the inactive piles require additional stabilization; if they do require stabilization, the (Appropriate State Regulatory Agency) will determine who or what legal entity possesses the responsibility for such stabilization. The owner or assignees will then be directed by the (Appropriate State Regulatory Agency) to undertake those measures necessary to satisfy this Regulation, and the owner or assignees shall follow a time-schedule approved by the (Appropriate State Regulatory Agency).

3. Whenever an active pile is officially reclassified as inactive after the effective date of this Regulation, the owners or assignees will notify the (Appropriate State Regulatory Agency) in writing of the change in status within 30 days of reclassification. The written notice will specify plans for disposal or stabilization subject to the approval of the (Appropriate State Regulatory Agency).

4. The (Appropriate State Regulatory Agency) will periodically inspect, or cause to be inspected, all inactive tailings piles to determine the effectiveness of stabilization procedures. The results of the inspection will be submitted to the (Appropriate State Regulatory Agency) and to the owner or assignees of the pile. In the event the (Appropriate State Regulatory Agency) determines that remedial measures or changes in methods are required to further protect the environment, they will make a determination as to whether or not new or revised plans for stabilization are required. If new or revised plans are required, the (Appropriate State Regulatory Agency) will require same from the owners or assignees following a time-schedule fitting the seriousness of the deficiencies. (Appropriate State Regulatory Agency) approval will then be modified to reflect the improved stabilization requirements.

REGULATION (continued)

5. All stabilization procedures shall provide for the following:

   a. Taking into consideration the types of natural materials at each site, piles shall be graded so that there is a smooth and gradual slope which insures, by virtue of its slope, that there shall be no harmful erosions and no depressions on the slope of the pile, where water will collect, seep into the pile, and thereby leach contaminants into the ground water. In the event that seepage and subsequent pollution of ground water is deemed possible, the (Appropriate State Regulatory Agency) will require the submission of possible control measures for their evaluation. Any water collected as a result of approved control measures shall be disposed of in a manner approved of by the (Appropriate State Regulatory Agency).

   b. The surface of inactive piles shall be covered with materials that prevent wind and water erosion. If the pile is adjacent to any watercourse that may reasonably be expected to erode the pile during periods of high water, the exposed surfaces shall be stabilized by riprap, dikes, reduction of grades, soil cover and vegetation, or any other combination of methods that will prevent erosion of the pile. The pile may be stabilized with materials such as concrete products, cement, chemicals, petroleum products, or other extraneous materials provided that these materials do not cause pollution and that the final configuration and appearance are determined to be compatible with the projected land-use as defined by the (Appropriate State Regulatory Agency).

   c. Access to the stabilized pile area shall be controlled by the owner or assignees and the area shall be properly posted in accordance with the appropriate regulations covering the handling, production, or possession of radioactive materials, All inactive tailings piles shall be fenced and posted to prevent public ingress.

d. Drainage ditches of sufficient size and durability shall be provided around the pile edges to prevent surface runoff from neighboring land from reaching and eroding the stabilized pile.

e. The owner or assignees should keep tailings piles out of natural drainage courses so as to reduce the need for long-term maintenance of diversion structures.

f. If irrigation is required on a stabilized tailings pile in order to maintain vegetation, it shall first be established to the satisfaction of the (Appropriate State Regulatory Agency) that no pollution of the ground water shall occur as a result of irrigation. The (Appropriate State Regulatory Agency) may specify that an observation well(s) be maintained down-gradient of any irrigated pile or of any large pile located in an area of relatively high precipitation where significant leaching of contaminants may be expected.

g. When an active tailings pond becomes inactive, the water remaining in the pond shall be disposed of in a manner consistent with regulations and approved by the (Appropriate State Regulatory Agency). After draining, the pond shall be graded and/or covered with acceptable materials that (1) prevent wind and water erosion and (2) eliminate depressions that would allow water to collect and seep through the stabilized area.

6. Prior written approval of the (Appropriate State Regulatory Agency) must be obtained before any tailings material is removed from any inactive tailings pile, and the (Appropriate State Regulatory Agency) shall maintain an inventory of all removed tailings, including disposition.

7. The owner or assignees of any tailings pile site shall give the (Appropriate State Regulatory Agency) written notice at least 30 days before any contemplated transfer of right, title, or interest in the site or material thereon by deed, lease, or other conveyance. The written notice shall include, but is not limited to, the name and address of the proposed owner or transferee, a description of the proposed land use and the quality and character of the tailings material involved. Prior to the (Appropriate State Regulatory Agency)

approval of the proposed action, it must be demonstrated to the satisfaction of the (Appropriate State Regulatory Agency) that the proposed action will not result in radioactive exposure(s) that exceed those specified by the applicable State and Federal regulations. Prior to assignment, the assignee shall be informed of all duties and responsibilities by the owner.

8. All stabilization plans and methods shall consider long-term maintenance requirements to insure protection of the environment which will be specified in the written plans required to comply with this Regulation. Such maintenance may include, but is not limited to, irrigation, clean-out and repair of ditches, repair of fences, reseeding, or replanting. The (Appropriate State Regulatory Agency) through periodic inspection of each pile, will evaluate the need for such remedial measures and will advise the owner or assignees if action is required.

9. The effective date of this Regulation shall be forty-five (45) days after the date of adoption.

10. Prior to consideration and adoption of this Regulation, the (Appropriate State Regulatory Agency) will conduct public hearings in order that any interested or affected persons may bring comments regarding this proposed Regulation to the attention of the (Appropriate State Regulatory Agency).

MR. STEIN: Are there any comments or questions?

If not, Mr. Dickstein.

MR. WILLIAMSON: We will have a chance to comment on the status?

MR. STEIN: Yes.

MR. WILLIAMSON: You want by the States?

MR. STEIN: By the States, yes. Did you want to comment now?

MR. WILLIAMSON: I just wanted to ask as to status where are we today. Do you want to consider that?

MR. STEIN: Yes, certainly. Go ahead.

MR. WILLIAMSON: I can update you on where we are in Wyoming on this. I think we have solved the problem possibly in a little different aspect.

Grant you, the one at Riverton still creates some problems because nobody owns it. Until somebody gets tied down to ownership, why, then something can be done. This is a matter of the company just not paying taxes on the land so the county is going to inherit it sooner or later and then you have somebody to work with.

But as far as all the rest of the mills that are still operating and under our land reclamation law for open pit mining, which these all are, the engineer in charge of land reclamation is going to every company and these are all of the lagoon type, if you wish to call it, not piling, not tailings stacked up in the air, they are in impoundments, and it is part of their reclamation program, and has been signed by all of them now, that they must cover these tailing lagoons when they stop working. In other words, they will be covered over with sufficient soil and reseeded. So we think that this will take probably the place of a model regulation unless we run into somebody who wants to stack it on top of the ground again.

That is about where we are at this time.

MR. DICKSTEIN: I now would like to call on Mr.--

MR. STEIN: Let's see if there are any other comments.

MR. DIBBLE: Mr. Stein, just one question. Is the State of Colorado going to explain what differences there are in their regulation as against this proposed model regulation?

MR. STEIN: We are going to have someone from Colorado scheduled later.

I also have a question for Mr. Williamson. I know this is a problem that we have with abandoned mines back East, but the notion of not having someone to work with often presents a most vexing and long-range pollution problem.

Now, I don't want to make any judgment of the situation at Riverton, but if this is really a problem and it presents an environmental problem, I just raise the question is it satisfactory just to wait to let nature take its course until the land goes back to the county or a public body. Because maybe they may not be too anxious to pick that up, recognizing the kind of problem they are going to have when they take it over. And the experience we have had with situations of that kind indicates that the problems tend to drag on and on.

Now, one of the questions that I would present to the conferees is either we pursue this or, if the problem rests the way it is and we haven't got a responsible party to move against, there may have to be a public project to take this. And I am not indicating that there should be, and I recognize if you come to that conclusion that someone is going to have to pay for it. The question is where the money is going to come from.

I just have this suggestion. It might be worthwhile if we could come to a judgment on how much it would cost and what we would have to do to handle the Riverton problem to see where we could look for the resources to do this job. I am just raising this, Art. I don't know.

Does anyone have any idea what it would take to clean up Riverton?

MR. SMITH: I would say at least on the order of about $1 million.

MR. STEIN: Pardon?

MR. SMITH: I say at least on the order of about $1 million.

MR. WILLIAMSON: Well, there is a possibility here you might investigate concerning this water pollution. We usually have construction funds that are begging and we give you back a million or so each year. We might take a look at those and utilize them somewhere along the line. You give us 70 percent under the new proposed legislation; maybe this will go a long ways towards it.

MR. STEIN: Well, again, Art, we are faced with the problem here, and I am not precluding that, although there may be some legal difficulties, but the difficulty is that without a responsible party in the State, even though it is 10 or 5 percent, one, you are going to need a sponsor for the project, and secondly, they are going to have to get up some kind of money. Now, whatever Federal funds are available, if you are thinking in terms of a matching program, you are going to have to come forward with some money in the State.

By the way, this may be a Wyoming problem, but the radiation problem, as Mr. Smith points out, is not one State's problem, because once this gets in the water you all have it. It just lasts. I think one of the things we should do is try to come up with possibly a more definitive recommendation on handling the Riverton problem. And one of the things we might do is let the Region work together with Wyoming and come up with a recommendation, possibly, that we can put into effect or explore and see if we can put into effect on this.

I suggest that there are two things you will have to indicate: one, how much it is going to cost; and, two, what you are going to do with the money, what kind of resources we will need and what we are going to come out with. And I would hope that the Region and Wyoming would work up that and come up with recommendations.

Mr. Dickstein.

MR. DICKSTEIN: I would now like to call on Mr. James Malaro of the Atomic Energy Commission.

Mr. Malaro.

JAMES MALARO

ASSISTANT CHIEF, MATERIALS BRANCH

U.S. ATOMIC ENERGY COMMISSION

WASHINGTON, D. C.

MR. MALARO: Thank you, Mr. Dickstein.

My name is James Malaro, Assistant Chief of the Materials Branch, U. S. Atomic Energy Commission, Washington, D. C.

My brief statement is as follows:

We appreciate the opportunity to participate in the seventh session of the conference on the Colorado River Basin.

Under recently enacted Atomic Energy Commission regulations, Title 10, Code of Federal Regulations, Part 50, Appendix D, implementing the National Environmental Policy Act of 1969, the AEC now has responsibility for evaluating the total environmental impact from AEC licensed new uranium mill operations regardless of whether the particular impact results from materials licensable under our regulations. Since it appears that stabilization and long-term care of tailings will significantly reduce the environmental impact from milling operations, we are requiring that new applicants for uranium mill licenses discuss their plans for stabilization and long-term care of these tailings as part of their environmental report.

J. Malaro

It has been and still is the AEC's position that tailings piles resulting from uranium mill operations should be stabilized so as to minimize water and wind erosion. We are particularly gratified to see that a major item for consideration at this session is a model State regulation dealing with stabilization and long-term maintenance and control of uranium mill tailings. We endorse the adoption of such a regulation by all of the States.

Among some of the approaches that are being considered by the AEC to deal with tailings from new mills is one which would require all uranium mill applicants, in addition to describing procedures for stabilization and long-term control of tailings, to enter into binding agreements which would assure such stabilization and long-term control. The model State regulation being considered here could provide a practical regulatory framework for implementing this approach. Such a model regulation might, for example, include a requirement that the mill operator post a bond or deposit sufficient funds in an escrow account to cover expected cost of stabilization and long-term care of tailings. It might also include a provision requiring that ownership of the land on which the tailings are deposited revert to the State at the termination of the milling operations.

We look forward to working with interested Federal and State agencies in developing practical methods for controlling uranium mill tailings and will continue to provide any assistance we can in developing effective methods for dealing with this problem.

Thank you.

MR. STEIN: Thank you.

Are there any comments or questions?

If not, thank you very much.

MR. DICKSTEIN: We would now like to proceed to the various States for any State presentation in the area of the tailings regulation.

First the State of Arizona.

MR. TABOR: None.

MR. DICKSTEIN: State of California?

MR. DIBBLE: We have no comments either.

MR. DICKSTEIN: Thank you.

State of Colorado.

MR. ROZICH: Mr. Jacoe has a statement.

P. W. JACOE, DIRECTOR
DIVISION OF OCCUPATIONAL
AND RADIOLOGICAL HEALTH
COLORADO DEPARTMENT OF PUBLIC HEALTH
DENVER, COLORADO

MR. JACOE: I am Mr. P. W. Jacoe, Director, Division of Occupational and Radiological Health, for the Colorado Department of Public Health, and I am going to attempt to give you some of the experiences that we have had in implementing the regulations which were adopted on December 12, 1966--

MR. STEIN: Mr. Jacoe, I wonder if you would put your microphone down a little. I think they are having trouble hearing you.

MR. JACOE: Thank you.

MR. STEIN: Thank you.

MR. JACOE: --and became effective the following January in 1967.

Actually, the impetus for getting into the stabilization of mill tailings was partly our own and partly because of the worry that industry had and mainly because of the great number of complaints that both the State and industry were getting because of blowing dust. As Mr. Stein mentioned, the water problems were very satisfactorily handled and settled by the time that we got into it, and the method that we used to stabilize tailings was merely to maintain the tailings in a position so that they wouldn't again pollute the water.

As I said before, we had a number of complaints and the telephone was very busy ringing there for a period of about a year, and every time the dust blew we had almost a direct line between western Colorado and Denver.

Prior to that time a number of studies were done, particularly on the blowing dust problem. Some were done by the AEC and there were some taken care of by the Colorado Department of Health.

I was going to read a short statement from Uranium Wastes in the Colorado Environment, but I will forget about that for now, but I do want to mention to this group here that we have done a complete edition of Uranium Wastes in Colorado's Environment in which the tailings problem is discussed, and it also includes the uranium mining problems that we got into clear back in 1948 and 1949. And if any of the conferees here wish a copy of that, just please let me know and I will see that they get one.

Along with the then Public Health Service--now, please excuse me if I get the names of some of the agencies a little mixed up because of so many changes there have been in the health department, but this was the Public Health Service--we did a three-phase study and that is to determine the amount of radioactivity that is in the air and whether the amounts would exceed any standards that we might apply.

In Phase One we found nothing of consequence.

In Phase Two we found something of interest, but probably of no consequence, and that was of the high gross alpha to the radium which was found. We have not pursued this any further, but it is at least of academic interest.

And then Phase Three was the determination of radon gas. And this particular study that I am referring to, I can call this one Phase Three, was done by the Atomic Energy Commission and a new method had to be developed for getting an integrated sample of radon gas and this whole method had been devised prior to this particular time. So that we did look for radon gas in one particular city in which a mill tailings pile existed and again we found that the radon gas didn't really exceed any standards.

So actually in relating to the levels that people are exposed to, you can see that what we have found so far has not posed a significant health hazard, but I particularly am not satisfied with the methods that were previously used because this was the first time that any of this work was done and perhaps the methods were crude.

Now, in preparing the regulations that we have, we had only the Monticello experience in which the AEC stabilized that mill tailings pile in 1961 and there were a number of other piles that have been stabilized in Africa. We got the reports from the African stabilization and found that they wouldn't very well apply to Colorado because of the different climatology. And this is very, very important, the climatology in Colorado, because actually what some people would call an afternoon thundershower is a cloudburst in western Colorado. So the area is very dry and the natural growth that you find there takes a long time to grow and you won't get very good natural cover.

The regulations were developed with the assistance of industry, I will say almost with the pressure of industry, because they realized very well that we did have a problem, and this is one thing that I would like to stress to those States who are considering adopting mill tailings regulations, is to work very closely with industry because these people have to foot the bill and they have got good engineering staffs and they can help you a great deal. In fact, I am sure that industry is the same in all States, but our Colorado group gave us a great deal of assistance and actually the regulations that they wrote and that were eventually adopted by the Board of Health were a little stronger than I had anticipated that they might be.

The implementation of the regulations took time. The plans had to be submitted before the Board of Health, and the Board of Health, of course, as many of you know, are mostly non-technical people, so that an explanation had to be given to these groups as to actually what was intended and what was planned and then getting the job done took additional time. So as Mr. Smith mentioned, we have been in business only about 4 or 5 years.

In the meantime, we had a discussion with a number of agronomists from Colorado State University and Mesa College at Durango concerning the growth of materials on tailings piles and just how much fertilization and water it would take, and they advised us that probably 6 to 10 inches of soil and generally grains would be the best, but they were doing a number of experiments. And actually we have one tailings pile which is being experimented on at this particular time and that is actually growing plants directly on the tailings. Of course a number of the active piles are doing the same thing. I have seen growth of grains that are waist high growing directly out of the tailings. I think they are fertilized and watered very frequently, but this is what it requires.

Now, what we try to do with regulations would be to make them as simple as possible so that they could be applied very easily and to leave them fairly wide open, because we didn't want to limit industry to any one particular method of stabilization. So that if anyone came up with something new, it could be applied, and this could be by adoption of the Board of Health or by permission of the Board of Health. We are very anxious to hear from others who might have some different ideas on how this could be done rather than just putting soil on and planting, because this is a very expensive process and particularly when not a great deal of soil is available.

This was done, by the way, I forgot to mention previously, in Colorado, but it was a very much simpler operation. It was a very large mill that had done custom milling for quite a number of years, and it was situated in an area where all they had to do was push some dirt from the surrounding hills onto the tailings pile and they imported some grass from Australia and planted it around there and it worked very well. This was about, oh, 4 or 5 miles west of Colorado Springs. They had a great deal of trouble with the blowing dust from this particular operation, and when they moved to Cripple Creek they stabilized that particular pile. So actually we did have one pile stabilized before the regulations took effect.

Actually the stabilization process has to be reported to the Board of Health very frequently. They want to know what the piles look like, if the stabilization is working, and this sort of thing, so that we do have people who are going out into the field to take a look at the piles to see if the growth is good and to determine if there is any washing or any places where it is unstabilized. You see, what we had in the back of our minds in stabilizing the tailings piles, really, was to prevent the washing, as I mentioned before, and to prevent the blowing dust.

And I think that there is one third thing that we should all remember--that a large tailings pile such as that is a nice pile of sand, and it can be used for a number of other purposes. And stabilization, of course, with dirt will prevent the use for those purposes. I am not going to mention some of the particular problems that we have, but most of you know that we do have quite a problem from the use of piles, as Mr. Smith mentioned, in one particular city.

We feel that the program is very effective, and in the time allotted us in 5 years it has done the job. We have not had a great number of telephone calls--well, we haven't had any--where the piles have been stabilized from blowing dust, and we are doing some sampling in the rivers. Of course we have to. We are an agreement State and we have to analyze the effluents from the active mills and also do some other work in the rivers, and we have found essentially the same thing that EPA has found, that the radium content has dropped. About the only thing that I can see that we have discovered is something that we knew right along— that the radium varies from time to time in the river, but this essentially, I think, is due to natural causes through smaller streams and to the amount of radium that the water picks up from the rocks and soils.

Now, I don't believe it would be advisable for anybody to feel that they are going to adopt tailings regulations for the control of uranium mill tailings piles and wave a magic wand and feel that the job is done, because I think there are certain responsibilities that a person has to accept. In adopting these regulations you have got to make periodic inspections, you have got to do a number of analyses, and there are a number of other things that you have to do. And hopefully, by the time that other States adopt such regulations, we may have some of the work done and give you some information that may be of value to you, and I will mention some of that just a little later in the presentation.

We do not consider this stabilization program that we have as a permanent method of stabilization. I think it would be foolish to do so. We don't know how long stabilization will last. The question has been raised about the owners of property, which I want to divert just a little bit from the-- I don't have a script here because I speak from notes. But I want to divert just a little bit from that— that we do have one particular tailings pile that did change hands between the time that the radium operation took place and the time it was stabilized. So we had no particular problem because we had in our regulations about the same thing that you see in most regulations— and you should have this in them— and that is that they must inform you ahead of time that there is a possibility that there will be a change of property so that the people will know beforehand that they will have this as part of their responsibility to stabilize the tailings that they are about to buy. Now, this occurred in one particular place, and I have a few slides from that one that I would like to show you in just a few minutes.

If I am taking too much time, would you please let me know?

MR. STEIN: No, go ahead. I wonder sometimes if you could bear in mind Mr. Dibble's question on how the Federal proposal differs from Colorado's regulation. That would be helpful.

MR. JACOE: Yes, sir.

MR. STEIN: If you could cover that before you are through.

Proceed in your own way.

MR. JACOE: Yes, sir.

We have found that occasionally you get washed out when we have floods and, of course, this is something that you have to be very careful with, because if it is allowed to continue you will have a very large area washed out and the cost of repairing that, and replanting it, etc., hauling in more dirt, would be quite high. So this is something that is all part of the responsibility.

As I mentioned before, I would like to go a little bit to the monitoring that we have done, and I mentioned the Colorado River, and just give you a few numbers. I have the computer readouts with me. If anyone is interested in looking at those later, they can.

Actually, we found 0.3 of picocurie per liter above the mill at Rifle and 0.3 above the mill at Climax and 0.2 below the mill at Climax. These are just average figures. You will have high ones and you will have low ones. So you see, there is no contribution to the river, so that this seemed to be very effectively cleared up by the program that had been in operation prior to 1966 or 1967.

P. W. Jacoe

The Dolores River gives us a little more problem because I think we have some radium getting in from some of the side streams in there. We found 0.2 above--well, 0.2 average, 0.2 picocurie above the Slick Rock mill tailings pile, 0.3 below, and then you find one as high as 0.82 below, And there is really no reason for it. This is the type of thing that you may throw out as a laboratory accident or you might include in as something that was washed in.

In the San Miguel River we found above Naturita, the Naturita mill, 0.3 of a picocurie per milliliter and one sample ran as high as 12.0, and there was absolutely no reason for this at all because there isn't a uranium mill in that area at all. There are some little mining mills up at Telluride and Placerville and that area up in through there.

So I could go through these figures and they wouldn't tell you very much because there are such fluctuations, and they cannot be directly related to tailings piles or to discharges from uranium mill tailings property. So the program in effect is certainly satisfactory.

I would like to mention something else that we have been doing. And this might be of advantage to you because a number of people want to use a tailings pile, particularly after the wonderful job that Bob Beverly did on what we call his golf course at Rifle, and it is really a good job. I am very sorry that I didn't bring the slides for Rifle, but I thought Bob would want to show you those and he didn't take them along either. So I don't have those with me.

But this is what we have done, and I will have this here for people to look at. I don't want to give you too many of the numbers because we have a commitment to write this up and publish it. But we are doing external gamma radiation measurements on a particular mill tailings pile where we measured the external gamma before the pile was covered, and after it was covered we went back and measured the external gamma. As you can see, we divided the pile off into grids--

MR. STEIN: Mr. Jacoe, you can read the paper. No one is going to steal your stuff and beat you to publication. (Laughter.)

Go ahead.

MR. JACOE: And we have the readings that were taken at the ground level and at waist level, about 3 feet above the ground level. Then after the dirt was put on we went back and did this in exactly the same spots and a few anomalies showed up. Sometimes we didn't get much reduction in gamma radiation, but actually the gamma levels were off by about one order of magnitude, which is pretty good. It reduced the external gamma.

Because on a tailings pile you would be well within the limits for film badging a person according to the radiation regulations.

And getting back to the original question about the proposed regulations, I don't want to actually compare them point for point because I don't believe I am able to at this time. I read them over once because they have been changed, but they are very similar to the Colorado regulations and they do apply to all mill tailings piles. I might add that I think that they are very good. I think that all States should adopt them if they can all adopt them in exactly the same manner and apply them in the same manner.

I am not prepared, Mr. Stein, to go into a direct comparison unless I have both of them before me, but I will say this, that they are very close to the regulations we have and we feel that ours are quite successful.

MR. ROZICH: Mr. Jacoe, I would like to point out, I don't know whether he has a copy of the latest draft, which I notice is the 13th, which was Sunday, and I believe comments were made on the draft of 1-7-72 that--

MR. DICKSTEIN: These comments were incorporated in the one of the 13th.

MR. ROZICH: I see.

MR. DICKSTEIN: Mr. Jacoe was very instrumental in these changes.

MR. ROZICH: All right.

MR. JACOE: I would like to bring out the usual projector. Perhaps it would show you just a little bit of what was being done if we show you--

MR. STEIN: Here is the point. I think sometime before the end of this perhaps you or Mr. Smith might get together with the conferees. As I understand, both you and Mr. Smith endorsed the Federal recommendation. I think you should give the conferees some kind of indication of what the differences are, and I think Mr. Smith indicated that there were improvements on the basis of your experience and your comments were incorporated.

But I think that would help us before we go into our discussion in executive session if we could have that.

MR. JACOE: I will be very glad to do that.

MR. STEIN: Thank you.

....Slides...

MR. JACOE: That is what it looked like before. These aren't my pictures, because I take very poor pictures. But part of the mill was being torn down. That was taken with a telephoto lens, but you can see the tailings pile there and water that has collected in some of the low spots.

This is looking across the Colorado River, and the ponds to the left have been dried up, and the little stream that you see in the middle is a discharge, I think, from the Grand Junction sewage disposal pond, and off to the right there we have an area that is being kept open for replacing any mill tailings that we might find laying around. Sometimes they seem to have found their way along the bases of foundations for homes, etc., as you might have heard or read in your newspapers. We have an area reserved for that and this will be another area that the tailings pile will be moved to, will be covered and will be planted.

Now, that shows the edge of the tailings pile going down to that pond, and then off to the left there is where we plan on having a new tailings pile which will be stabilized.

I might mention, too, that this particular company, regarding a question that was asked before, did set something aside on per ton of uranium produced for tailings control, so that when they shut down the plant they had a certain amount of money left over for control, and they immediately went in to control their tailings pile. This was an excellent suggestion that was made here a few minutes ago.

And that is a telephoto lens copy of the whole thing. You can see how the pile is being leveled off there, and this is the Colorado River directly at the bottom of this light, and back there is an intake canal which was used for milling operations.

And again I think that is in back, I don't know for sure, but it shows about the same thing and you can see the extent of the pile.

Now there it is all covered over and smoothed off. And this was taken with a telephoto lens, but at the edge there you can see the riprap that was put in, and these are large chunks of concrete and the concrete is put along dirt. Now, the extreme edge that you see there is a dirt road, automobile road, so that the actual tailings extend back about, oh, perhaps 25 or 30 feet.

Now you can see that a little closer, and you can see the area that they have leveled off. Finding dirt was a little difficult for this operation, but the chunks of concrete are there and you can see the road a little closer.

This shows the ponds after they were dried up and that again is in backwards. I think that you can begin to see some of the growth off to the right there that has been put on there. I think most of that is volunteer; it is weeds.

And again there is some of the growth on the tailings pile taking place and it's beginning to, well, look like my backyard does in August with all of the weeds on it, But you can see that it does actually work and there is growth and that most of it is volunteer growth. Some of that is planted, of course.

Now, that is a tailings pile taken in the wintertime. You can see the snow. That is the one at Naturita, and it just gives you a general idea of what it looked like before it was stabilized.

And you can see again the riprapping material that was put along the side of the river. And I think there are some pretty good figures on flood stages and then, of course, before you get to the tailings pile there is a lot of dirt piled for a roadway going around the pile.

MR. STEIN: Mr. Jacoe, do the tailings go up to the riprap or is there a barrier between the tailings and that riprap?

MR. JACOE: No, there is a barrier between the tailings and the riprap. The barrier on this facility will be an automobile road for them to get around to the other side and so that they can fill in washes, because we did have one area that washed pretty badly on this particular pile.

Does that answer your question, sir?

MR. STEIN: Yes. In other words, there is no radioactive material right up against the riprap? As a matter of fact, that road is not tailings material, is that right?

MR. JACOE: That is correct, sir, yes.

MR. STEIN: Thank you.

MR. JACOE: Now you can begin to see how it looks with some dirt on it. And I had forgotten to mention that we always ask for a ditch to be put along the top when a tailings pile is being stabilized and it slopes down towards the river, and we put a ditch along the top to divert water that might happen to run down off of the surrounding hills and create a wash, so that all of them do have this ditch there to prevent that.

And this is the same pile and the dirt begins to look pretty good. Actually, they planted grains on this one, and we had rye that was about, oh, I would say 3 feet high there at one time. It does demand a little irrigation because it doesn't rain very much here.

Then here it is with the growth on it. That looks to me like the Rifle mill. Bob Beverly, could you help me with that?

MR. BEVERLY: Old Rifle.

MR. JACOE: That is the old Rifle mill. That is Bob Beverly's golf course I was telling you about, and it is a very beautiful piece of work there. You drive along there and you see the sea of green there in the summertime, you would never know that there was a tailings pile there. This, by the way, was the first one that was stabilized.

Now, this is the one that I was mentioning a few minutes ago that belonged to a different company, and it looked like this alongside the road. The tailings had blown from the west and had increased almost down to the fence. This seemed to be one of the easier ones to stabilize because it was in flat country, and the pile was put up about, oh, maybe 20 feet off the surface of the ground and was fairly level. It didn't require much work to get it level enough to plant something on. And I think practically all of the growth on this is volunteer growth. They did plant a few of the grasses and weeds.

And that is the same pile taken in the wintertime. It doesn't show very much.

Now here is what I wanted to show you. This is the riprapping there at Slick Rock, if I am not mistaken. You can see that now where the pile had been removed, it was almost down to the river at one time and had been pushed back and riprapped in that particular manner to prevent the tailings from being washed down.

And here it is with--you can see part of the riprapping down there and there it is with the growth on it, which looks pretty good. It does prevent erosion pretty well and prevents water from being washed into the river.

Now this is an experiment of ours and it is not--it hasn't been approved by the Board of Health, but a number of universities and colleges and the U. S. Bureau of Mines are experimenting on this. You can see that is a very steep pile and they are trying to grow directly on the tailings. It requires a great deal of water, some fertilization, but you can see that it can be done. The area off to the left there just above the locomotive was very steep, and they are using these mats that they have seeds in to plant in that area. Mats are about the only thing that will grow in something that steep. That pile, of course--I feel when the Board of Health approves the eventual stabilization of that--will have to be leveled off and stabilized in the other manner, but they wanted to leave this open for some experimentation to see what will grow best and how it will grow directly on the pile itself. We have information from the universities that it takes 20 to 40 years of continuous growth on a tailings pile with no dirt for enough dirt and mulch to be built up to maintain a growth of natural vegetation and we just don't feel we can wait that long, but it is an experiment.

And I guess that is it for the slides.

MR. STEIN: Are there any comments or questions?

Just one question, Mr. Jacoe. Whatever happened to the method that they were considering years ago of putting some petroleum derivative on those piles? I guess that didn't pan out too well?

MR. JACOE: No, that didn't pan out too well. We talked to the highway department. It only lasts for about a year and once you get a wash it just washes off. It is very expensive also.

MR. STEIN: Thank you.

Any other comments or questions?

If not, thank you.

MR. DICKSTEIN: Thank you, Mr. Jacoe. We will move on with the States.

Nevada.

ROLAND D. WESTERGARD

STATE ENGINEER

DIVISION OF WATER RESOURCES

CARSON CITY, NEVADA

MR. WESTERGARD: Mr. Chairman, under date of yesterday the interested Nevada agencies have submitted a letter to you on this subject, and rather than read it in detail I will just submit it for the record and just read the outline of what it says. Essentially it goes to the terminology and I think can be summarized by saying that we suggest a little more positive rather than permissive terminology in the regulation.

We also have some concern about the section that has been discussed here by the AEC representatives and others requiring long-term maintenance requirements and just how this can be made effective.

That generally is the text of our letter.

MR. STEIN: Without objection, that letter will appear in the record at this point as if read.

(The above-mentioned letter follows:)

STATE OF NEVADA
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GEORGE ZAPPETTINI
State Forester
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THOMAS WILSON
Coordinator
State Comprehensive Health Planner

February 14, 1972

Murray Stein, Chairman
Conference in the Matter of Pollution of the
Interstate Waters of the Colorado River
U.S. Environmental Protection Agency
Office of the Administrator
Washington, D.C. 20460

Re: Regulations for the Stabilization of Radioactive Tailings Piles

Dear Mr. Stein:

Interested Nevada state agencies have reviewed the model regulation for the stabilization of radioactive tailings piles and offer the following comments:

1. Under the section titled DEFINITIONS, the definition "Stabilization - Encompasses all measures necessary to insure immediate and future protection of the environment and to eliminate hazards to health and welfare with a minimum of future maintenance. In no case shall the stabilized pile exceed or cause to be exceeded applicable health or other environmental standards", is nebulous and does not speak to the process of stabilizing.

It is suggested the definition be reworded to state: "Stabilization - The confinement or containment of tailings piles be vegetative, mechanical, physical or other measures to prevent erosion. In no case shall the stabilized pile exceed or cause to be exceeded applicable health or other environmental standards."

2. Page 5, paragraph 4, lines 8 and 10. The words "should" be replaced by "shall" to make plan submission and approval mandatory. "...No surface disposal [should] shall be allowed until the (Appropriate State Regulatory Agency) has approved the stabilization plans. The plans [should] shall be submitted to the (Appropriate State Regulatory Agency) at least 90 days prior to the scheduled start-up of a mill."

3. Page 5, paragraph 5, line 3 reads "...The results of the inspection will be submitted to the (Appropriate State Regulatory Agency) and to the owner or assigness of the pile..." The phrase "to the (Appropriate State Regulatory Agency) and..." could be deleted. Unless there is more than one state regulatory agency involved it would seem reasonable the enforcing agency would retain a copy of its own report.

4. Page 6, paragraph 6b, first line, reads "The surface of inactive piles shall be covered with materials that prevent wind and water erosion..." It is suggested this line be amended to read "The surface of inactive piles shall be planted with suitable vegetation or covered with materials [that] to prevent wind and water erosion..." to provide an option.

5. Page 7, paragraph 6e, reads "The owner or assignees should keep tailings piles out of natural drainage courses so as to reduce the need for long-term maintenance of diversion structures." Because long-term maintenance of diversion structures is next to impossible to practice or enforce, this section should not be optional but mandatory. It is suggested this section be amended to read "The owner or assignees [should] shall keep tailings out of natural drainage channels."

6. Paragraph 6, tailings placed on unstable soil formations can produce slides or subsidences which in turn produce adverse changes in nautral drainage channels. It is suggested an additional subsection h. be included to read "No tailings piles shall be placed on unstable soil formations that will result in a displacement of these formations."

7. Page 8, paragraph 9, this section requires long-term maintenance requirements but does not establish the responsible entity. Often mining companies, through the mining claim procedures, hold no more than a possessory interest in the public lands from which they mine and on which they place their tailings. At the end of operations they may abandon the land and terminate partnerships, dissolve corporations, etc. There are no assignees, the government simply gets the land back. In these cases who is responsible for the maintenance? In addition, who is responsible in the event of a relocation by another entity?

Sincerely,

Roland Westergard
Conferee

RW/gm

cc: E. G. Gregory
Elmo J. DeRicco
Don Paff

MR. DICKSTEIN: Thank you, sir.

New Mexico?

MR. SLINGERLAND: No statement.

MR. DICKSTEIN: Thank you.

Wyoming?

MR. WILLIAMSON: I don't believe I have too much to add to what I previously mentioned of our procedure. It may be necessary for some type of additional regulation to handle underground mining. Our present land reclamation will tie down all surface operations, but if somebody starts a deep shaft mine then we have got another problem.

MR. DICKSTEIN: Thank you, Art.

That concludes the tailings. Are there any further questions?

I turn it back to you, Mr. Chairman.

MR. STEIN: If Utah appears before we come back from our recess, which we are going to take very shortly, we will let them talk about this. But frequently people ask what does a conference accomplish. I think that possibly the conversations or the discussions we first had with the uranium milling industry on this radioactivity problem contrasted with what we have heard today will be like, I think, day and night. But you can read the record for yourself.

Maybe it is the times or maybe it is the push that we have had.

Again, I feel that we have generally had, with the cooperation of the States, the industry and AEC, a very successful program in abating water pollution from any of the uranium milling operations. The radiation levels are way, way, way down and under control. However, to keep this in perspective, I think we have to recognize that we are dealing with a residual problem as far as the water pollution people are concerned, that being the control of these tailings piles. I think the comments here have indicated that there has been a considerable amount of experience, a considerable amount of experimentation and successful operation, and that we probably have the tools at hand to be able to handle this. I hope the conferees will be able to come up with something relatively positive on this issue.

We will stand recessed for 10 minutes.

(RECESS)

MR. STEIN: Let's reconvene.

Before we go on, we would like to hear from Mr. Tabor of Arizona.

Mr. Tabor.

MR. TABOR: Mr. Chairman, I just wanted to make a statement that Arizona has passed a law relating to radiological wastes and tailings and has regulations concerning same. They were, quite frankly, plagiarized from Colorado. (Laughter.)

MR. STEIN: Are there any other comments or questions?

I would like to reserve one other thing. I think Mr. Thatcher of Utah is on his way and probably might be having airplane trouble, but if he comes we will call on him, too, for his contribution on the tailings problem.

We would like to move on now to the salinity problem, and with that I would like to call on Mr. O'Connell.

RICHARD O'CONNELL, DIRECTOR
ENFORCEMENT DIVISION, REGION IX
U. S. ENVIRONMENTAL PROTECTION AGENCY
SAN FRANCISCO, CALIFORNIA

MR. O'CONNELL: Thank you, Mr. Chairman.

As you mentioned, the other principal topic of this session of the conference is the mineral quality or salinity of the waters of the Colorado River Basin. This subject has been the subject of extensive investigation by the Environmental Protection Agency and its predecessor agencies over the past few years. This work was carried out at the direction of and with the guidance of this conference.

These studies have been completed and the Environmental Protection Agency technical staff is prepared at this time to report to the conferees on their findings.

I would like, therefore, to call on Mr. Russell Freeman of the Environmental Protection Agency Region IX office, who with the assistance of others that he will introduce will present these findings at this time.

Mr. Freeman.

L. RUSSELL FREEMAN
DIRECTOR, PACIFIC OFFICE
U. S. ENVIRONMENTAL PROTECTION AGENCY
HONOLULU, HAWAII

MR. FREEMAN: Thank you. Mr. Chairman, Mr. O'Connell.

My name is Russell Freeman. I am presently the Director of the Environmental Protection Agency's Pacific Office in Honolulu. However, during the course of the work which we will be reporting to you in the next few moments, I served first of all as Chief of the project's salinity unit located at Denver, Colorado, and later as Deputy Director for the Colorado River Basin Project of the Federal Water Pollution Control Administration.

Our presentation this morning is contained in a report entitled Report on the Mineral Quality Problem in the Colorado River Basin. This consists of a summary report and four appendices. I will present an introduction and I will also present at a later time the conclusions and recommendations from this report. Other parts of the report will be presented by Mr. William C. Blackman of our Denver Office, by Mr. James Vincent, also of our Denver Office, and by Mr. Jim Russell from our San Francisco Office. In the interest of time, we will present only a very brief summary of the material contained in this report, and for those of you who wish more detailed information the report is available in the foyer.

However, Mr. Chairman, we would like to have the entire report in the conference transcript.

MR. STEIN: Without objection, the report in its entirety will be included in the record as if read.

(The above-mentioned report and appendices follow:)

THE MINERAL QUALITY PROBLEM
IN THE COLORADO RIVER BASIN

SUMMARY REPORT

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGIONS VIII AND IX

1971

THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency was established by Reorganization Plan No. 3 of 1970 and became operative on December 2, 1970. The EPA consolidates in one agency Federal control programs involving air and water pollution, solid waste management, pesticides, radiation and noise. This report was prepared over a period of eight years by water program components of EPA and their predecessor agencies--the Federal Water Quality Administration, U.S. Department of Interior, April 1970 to December 1970; the Federal Water Pollution Control Administration, U.S. Department of Interior, October 1965 to April 1970; the Division of Water Supply and Pollution Control, U.S. Public Health Service, prior to October 1965. Throughout the report one or more of these agencies will be mentioned and should be considered as part of a single agency--in evolution.

PREFACE

The Colorado River Basin Water Quality Control Project was established as a result of recommendations made at the first session of a joint Federal-State "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries," held in January of 1960 under the authority of Section 8 of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.). This conference was called at the request of the States of Arizona, California, Colorado, Nevada, New Mexico, and Utah to consider all types of water pollution in the Colorado River Basin. The Project serves as the technical arm of the conference and provides the conferees with detailed information on water uses, the nature and extent of pollution problems and their effects on water users, and recommended measures for control of pollution in the Colorado River Basin.

The Project has carried out extensive field investigations along with detailed engineering and economic studies to accomplish the following objectives:

(1) Determine the location, magnitude, and causes of interstate pollution of the Colorado River and its tributaries.

(2) Determine and evaluate the nature and magnitude of the damages to water users caused by various types of pollution.

(3) Develop, evaluate, and recommend measures and programs for controlling or minimizing interstate water pollution problems.

In 1963, based upon recommendations of the conferees, the Project began detailed studies of the mineral quality problem in the Colorado River Basin. Mineral quality, commonly known as salinity, is a complex Basinwide problem that is becoming increasingly important to users of Colorado River water. Due to the nature, extent, and impact of the salinity problem, the Project extended certain of its activities over the entire Colorado River Basin and the Southern California water service area.

The more significant findings and data from the Project's salinity studies and related pertinent information are summarized in the report entitled, "The Mineral Quality Problem in the Colorado River Basin." Detailed information pertaining to the methodology and findings of the Project's salinity studies are presented in three appendices to that report--Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality," Appendix B. "Physical and Economic Impacts," and Appendix C, "Salinity Control and Management Aspects."

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CHAPTER I. INTRODUCTION

STATEMENT OF PROBLEM

The Colorado River system carries a large salt burden (dissolved solids) contributed by a variety of natural and man-made sources. Depletion of streamflow by natural evapotranspiration and by comsumptive use of water for municipal, industrial, and agricultural uses reduces the volume of water available for dilution of this salt burden. As a result, salinity concentrations in the lower river system exceed desirable levels and are approaching critical levels for some water uses. Future water resource and economic developments will increase streamflow depletions and add salt which in turn will result in higher salinity concentrations.

As salinity concentrations increase, adverse physical effects are produced on some water uses. These effects result in direct economic losses to water users and indirect economic losses to the regional economy. Unless salinity controls are implemented, future increases in salinity concentrations will seriously affect water use patterns and will result in large economic losses.

STUDY OBJECTIVES

The objectives of the salinity investigations summarized in this report were to provide answers to the following questions:

> What are the nature and magnitude of the major causes of the salinity build-up in the Colorado River and its tributaries?
>
> What future changes in salinity concentrations may be expected if no controls are implemented?
>
> What are the present physical and economic impacts of salinity on water uses, and how will these change in the future?
>
> What measures may be feasible for control and management of salinity in the Colorado River system?
>
> What are the economic costs and benefits associated with various levels of salinity control?
>
> What is the most practical approach to basinwide control and management of salinity?

What action must be taken to implement a basinwide salinity control and management program?

SCOPE

The Colorado River Basin Water Quality Control Project (hereinafter referred to as the Project) was established in 1960 by the Division of Water Supply and Pollution Control, U. S. Public Health Service (predecessor to the Federal Water Quality Administration). The Project was charged with the responsibility for identifying and evaluating the most critical water pollution problems in the Basin. Initial emphasis was placed upon evaluation and control of pollution resulting from uranium mill operations.

As a result of early Project investigations, salinity was identified as a pressing water quality problem which warranted detailed study. In 1963, the Project initiated salinity investigations directed toward answering the questions outlined above. This report summarizes the results of those investigations.

Salt sources contributing to the salinity problem are located throughout the Colorado River Basin. A large volume of water is exported from the Lower Colorado River to areas of Southern California. For these reasons, the geographical area covered by the Project included the entire Colorado River Basin and the Southern California water service area. Colorado River water is also utilized by Mexico. However, investigation of the effects of salinity on Mexican water uses was not within the scope of this study.

A broad range of studies was carried out which involved an array of scientific disciplines including hydrology, chemistry, mathematics, computer science, soil science, geology, civil, sanitary and agricultural engineering, and economics. The Project studies included intensive, short-term water quality field investigations, long-term water quality monitoring, mathematical simulation of water quality relationships, reconnaissance level evaluation of specific salinity control measures, and detailed economic studies. In addition to the Project's efforts in these areas, much input was provided by other Federal and State agencies and institutions, some of which were financially supported by the Federal Water Quality Administration (FWQA).

The data and recommendations contained herein are specifically related to the Colorado River Basin. However, the basic approach and methodology developed for evaluation of the physical and economic effects of salinity are considered applicable to many other areas of the West. Salinity control measures developed for the Basin may also be applicable to other areas with similar conditions.

It cannot be emphasized too strongly that if this report has erred in regard to estimated projections of salinity increases with the associated economic losses therefore, the errors have been in the direction of minimizing adverse effects. The actual effects are likely to be more severe than these figures indicate.

AUTHORITY

The Federal Water Quality Administration, U. S. Department of the Interior, formerly the Federal Water Pollution Control Administration, has primary responsibility for implementing national policy for enhancement of the quality of the Nation's water resources through the control of pollution. This policy has been spelled out over the past 14 years in a series of legislative acts which are described as the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et seq.). Section 10(d) of this Act authorizes the Secretary of the Interior, ... "whenever requested by any State water pollution control agency..." if such request refers to pollution of waters which is endangering the health or welfare of persons in a State other than in which (the source of pollution) originates, ..."to call a conference..." of the State or States which may be adversely affected by such pollution." Section 10 authorizes the Secretary to recommend "necessary remedial action" and also provides various legal steps that may be taken to abate pollution if remedial action is not taken in a reasonable period of time.

Under the provision of Section 10 of the Act, the initial session of the "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries" was held on January 13, 1960. The conference was requested by six of the seven Basin States. Five additional formal sessions of the conference and three technical sessions were held from 1960 to 1967. These sessions provided assignments to the Project for developing recommendations of remedial action to abate pollution.

Added impetus was given to the Project's salinity investigations on October 2, 1965 by passage of the Water Quality Act of 1965 (P.L. 89-234). This Act amended Section 10 of the Federal Water Pollution Control Act to provide that the States establish water quality standards for all interstate waters. Subsequent difficulties, encountered in establishing suitable salinity criteria as a part of these standards, pointed out the need to complete various aspects of the Project's investigations in order to provide the basis for establishing such standards.

CHAPTER II. SUMMARY OF FINDINGS AND RECOMMENDATIONS

SUMMARY OF FINDINGS

1. Salinity (total dissolved solids) is the most serious water quality problem in the Colorado River Basin. Average annual salinity concentrations in the Colorado River presently range from less than 50 mg/l in the high mountain headwaters to about 865 mg/l at Imperial Dam, the last point of major water diversion in the United States. Salinity adversely affects the water supply for a population exceeding 10 million people and for 800,000 irrigated acres located in the Lower Colorado River Basin and the Southern California water service area. Salinity also adversely affects water uses in Mexico and in limited areas of the Upper Colorado River Basin.

2. Salinity concentrations in the Colorado River system are affected by two basic processes: (1) salt loading, the addition of mineral salts from various natural and man-made sources, and (2) salt concentrating, the loss of water from the system through evaporation, transpiration, and out-of-basin export.

3. Salinity and stream flow data for the 1942-1961 period of hydrologic record were used as the basis for estimating average salinity concentrations under various conditions of water development and use. Assuming repetition of this hydrologic record, salinity concentrations at Hoover Dam would average about 700 mg/l and 760 mg/l under 1960 and 1970 conditions. If development and utilization of the Basin's water resources proceed as proposed and if no salinity controls are implemented, average annual salinity concentrations at Hoover Dam would increase to about 880 mg/l in 1980 and 990 mg/l in 2010. Comparable figures at Imperial Dam are 760 mg/l and 870 mg/l under 1960 and 1970 conditions, and 1060 mg/l and 1220 mg/l under 1980 and 2010 conditions. If future water resource development in the Basin were to be limited to completion of projects currently under construction, it is estimated that average annual salinity concentrations for 1980 and subsequent years would increase to only about 800 mg/l at Hoover Dam and 920 mg/l at Imperial Dam.

4. It is estimated that if the 1942-1961 period of hydrologic record were repeated under conditions comparable to when the Colorado River was in its natural state, salinity concentrations at the site of Hoover Dam would average about 330 mg/l. Because of man's influence, average concentrations at this point more than doubled

(697 mg/l) under 1960 conditions and will triple by 2010 (990 mg/l), if presently planned development and utilization of water resources occurs. Reservoir evaporation and irrigation will account for almost three-fourths of the salinity increase between 1960 and 2010.

5. Under 1960 conditions, natural sources accounted for 47% of the salinity concentrations at Hoover Dam. The remainder was accounted for by irrigation (37%), reservoir evaporation (12%), out-of-basin exports (3%), and municipal-industrial uses (1%).

6. As salinity concentrations rise about 500 to 700 mg/l, the net economic return from irrigated agriculture begins to decrease because of increased operating costs and reduced crop yields. At levels above 1,000 mg/l, the types of irrigated crops grown may be limited, and more intensive management of irrigation practices is necessary to maintain crop yields. At levels exceeding 2,000 mg/l, only certain crops can be produced by adopting highly specialized and costly irrigation management practices. Municipal and industrial water users incur increasing costs as salinity levels increase above 500 mg/l, the maximum level recommended in the U. S. Public Health Service Drinking Water Standards.

7. The present annual economic detriments of salinity are estimated to total $16 million. If water resources development proceeds as proposed and no salinity controls are implemented, it is estimated that average annual economic detriments (1970 dollars) would increase to $28 million in 1980 and $51 million in 2010. If future water resources development is limited to those projects now under construction, estimated annual economic detriments would increase to $21 million in 1980 and $29 million in 2010. Detriments to water users in Mexico and to recreation and fishery users in the Salton Sea are not included in the estimates.

8. More than 80 percent of the total future economic detriments caused by salinity will be incurred by irrigated agriculture located in the Lower Basin and the Southern California water service area and by the associated regional economy. About two-thirds of these detriments will be incurred directly by irrigation water users and the remainder will be incurred indirectly by other industries associated with agriculture.

9. Alternatives for salinity control in the Colorado River Basin include:

    a. Augmentation of Basin water supply. This could be achieved by importation of demineralized sea water, importation of fresh water from other basins, or utilization of weather modification techniques to increase precipitation and runoff. This alternative should be considered as a possible long-term solution to the salinity problem.

b. Reduction of salt loads. This could be achieved by impoundment and evaporation of saline water from point sources, diversion of runoff and streams around areas of high salt pickup, improvement of irrigation and drainage practices, improvement of irrigation conveyance facilities, desalination of saline discharges from natural and man-made sources, and desalination of water supplies at points of use with appropriate disposal of the waste brine. A basinwide salt load reduction program has been developed which would reduce the salt load contributed by five large natural sources and twelve irrigated areas totaling 600,000 acres. If fully implemented, it is estimated that this program would reduce average salinity concentrations at Hoover Dam by about 250 mg/l in 1980 and about 275 mg/l in 2010.

c. Limitation of further depletion of Basin water supply. This could be achieved by curtailment of future water resources development. Such action would minimize both future increases in salinity levels and the adverse economic impact of such increases.

10. A basinwide salt load reduction program appears to be the most feasible of the three salinity control alternatives. The scope of such a program will depend upon the desired salinity objectives. Partial implementation of the other two alternatives would increase the effectiveness of the salt load reduction program.

11. A basinwide salt load reduction program designed to minimize total salinity costs (detriments plus control costs) would have an estimated average annual cost of $7 million in 1980 and $13 million in 2010 (1970 dollars). Implementation of this program could limit salinity concentrations at Hoover Dam to approximately 1970 levels while allowing planned water resource development to proceed. The direct salinity control benefits (avoidance or mitigation of expected future salinity detriments) of such a program are estimated to total $11 million in 1980 and $22 million in 2010 (1970 dollars).

RECOMMENDATIONS

It is recommended that:

1. A salinity policy be adopted for the Colorado River system that would have as its objective the maintenance of salinity concentrations at or below levels presently found in the lower mainstem.

2. Specific water quality standards criteria be adopted at key points throughout the basin by the appropriate States, in accordance with the Federal Water Pollution Control Act. Such criteria should be consistent with the salinity policy and should assure the objective of keeping the maximum mean monthly salinity concentrations at Imperial Dam below 1000 mg/l. These criteria should be adopted by January 1, 1973.

3. Implementation of the recommended policy and criteria be accomplished by carrying out a basin-wide salinity control program concurrently with planned future development of the basin's water resources.

CHAPTER III. DESCRIPTION OF AREA

PHYSICAL DESCRIPTION

The Colorado River is situated in the southwestern United States and extends 1,400 miles from the Continental Divide in the Rocky Mountains of north central Colorado to the Gulf of California (Figure 1). Its river basin covers an area of 244,000 square miles, approximately one-twelfth of the continental United States. The Colorado River Basin includes parts of seven states; Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming. About one percent of the Basin drains lands in Mexico.

The Colorado River rises on the east slope of Mount Richthofen, a peak on the Continental Divide having an altitude of 13,000 feet, and flows generally southwestward, leaving the United States at an elevation of about 100 feet above sea level. The Colorado River Basin is composed of a complex of rugged mountains, high plateaus, deep canyons, deserts and plains. Principal physical characteristics of the region are its variety of land forms, topography and geology.

The Colorado River Compact of 1922 established a division point on the Colorado River at Lee Ferry, Arizona, to separate the Colorado River Basin into an "Upper Basin" and a "Lower Basin" for legal, political, institutional and hydrologic purposes. Lee Ferry is located about one mile below the confluence of the Paria River and approximately 17 miles downstream from Glen Canyon Dam. The Upper Basin encompasses about 45 percent of the drainage area of the Colorado River Basin.

In addition to the Colorado River Basin, the Project's investigations covered the area of southern California receiving Colorado River water. This area of about 15,400 square miles includes the Imperial and Coachella Valleys which surround the Salton Sea as well as the metropolitan areas of Los Angeles and San Diego.

CLIMATE

Climatic extremes in the Basin range from hot and arid in the desert areas to cold and humid in the mountain ranges. Precipitation is largely controlled by elevation and the orographic effects of mountain ranges. At low elevations or in the rain shadow of coastal mountain ranges, desert areas may receive as little as 6 inches of precipitation annually, while high mountain areas may receive more than 60 inches.

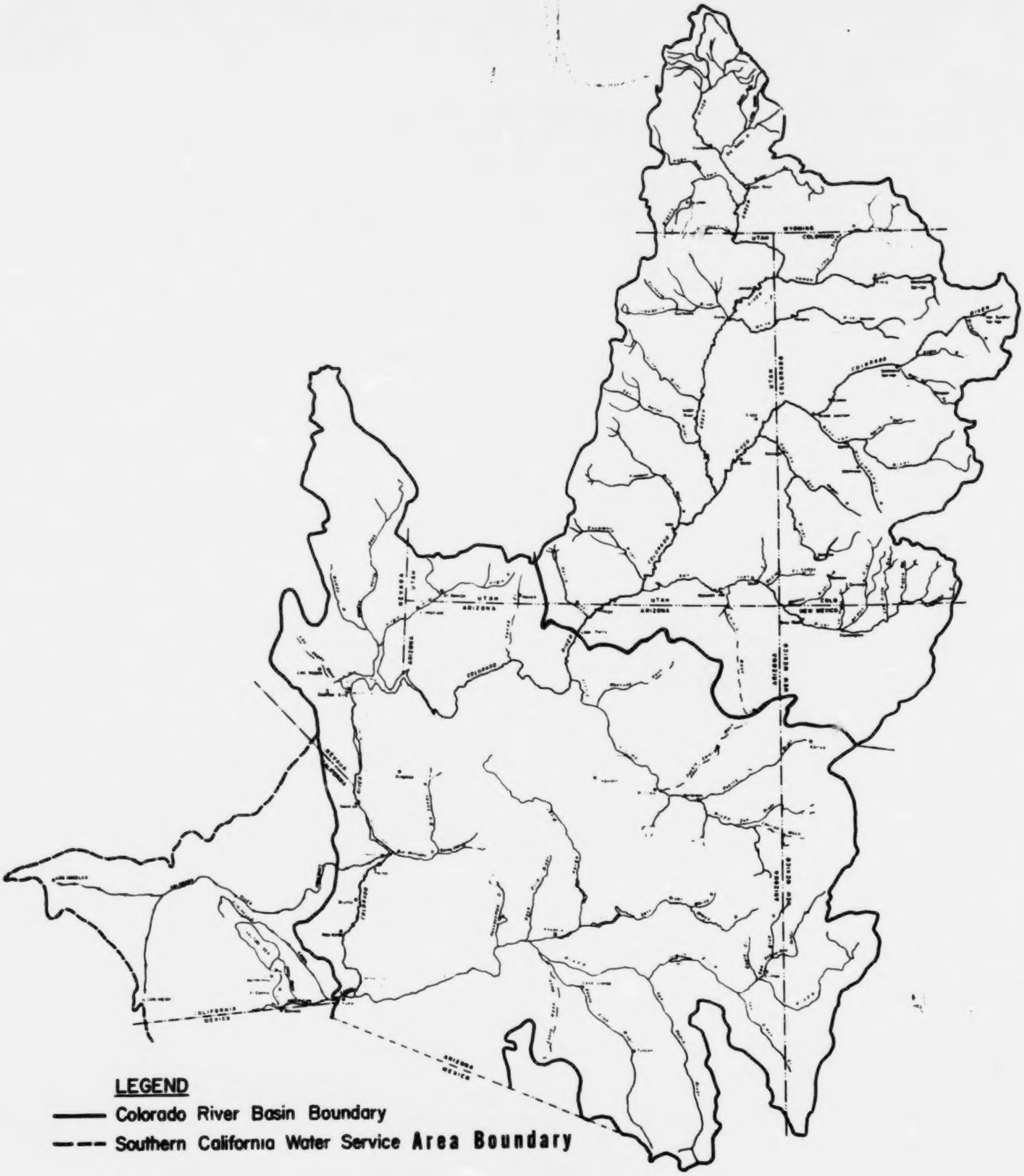
LEGEND
Colorado River Basin Boundary
Southern California Water Service Area Boundary

Figure 1 Colorado River Basin and Southern California Water Service Area

Basin temperatures range from temperate, affording only a 90-day growing season in the mountain meadows of Colorado and Wyoming, to semi-tropical with year-round cropping in the Yuma-Phoenix area. On a given day, both the high and low temperature extremes for the continental United States frequently occur within the Basin.

In the southern California water service area, the climate of the area surrounding the Salton Sea is hot and arid, while the climate of the coastal metropolitan areas is moderated by proximity to the Pacific Ocean.

POPULATION AND ECONOMY

The Colorado River Basin is sparsely populated. In 1965 the estimated population was nearly 2.25 million. The average density was about nine persons per square mile compared with a national average of 64. Eighty-five percent of the population lived in the Lower Basin. About 70 percent of the Lower Basin population resided in the metropolitan areas of Las Vegas, Nevada, and Phoenix and Tucson, Arizona. The population of the Colorado River Basin is estimated to triple by 2010.

The southern California water service area contained an estimated eleven million people in 1965. Most of the population was concentrated in the highly urbanized Los Angeles-San Diego metropolitan area.

The economy of the Basin is based on manufacturing, irrigated agriculture, mining, forestry, oil and gas production, livestock and tourism.

The present economy of the Upper Basin is largely resource oriented. This orientation is not restricted entirely to agriculture, forestry and mining, but includes the region's recreational endowment and the associated contribution to basic income. The mineral industry overshadows activities of the agricultural and forestry sectors. The major effects of outdoor recreation and tourism are reflected in the tertiary or non-commodity producing industries which as a group contribute the greatest share to total Upper Basin economic activity.

In the last two decades, the economy of the Lower Basin has experienced a significant transition from an agricultural-mining base to a manufacturing-service base. Growth in the manufacturing sectors has been one of the major factors in the overall economic growth of the Lower Basin. Important manufacturing categories are electrical equipment, aircraft and parts, primary metals industries, food and kindred products, printing and publishing, and chemicals.

Agriculture continues to play an important role in the southern California economy amidst the fast-growing industrial and commercial activity. Manufacturing is the most important industrial activity and principally includes production of transportation equipment (largely aircraft and parts), machinery, food and kindred products, and apparel. Agriculture accounts for about three percent of the total employment, manufacturing for an estimated 30 percent, and trades and services for approximately 42 percent.

WATER RESOURCES

An average of about 200 million acre-feet of water a year is provided by precipitation in the Colorado River Basin. All but about 18 million acre-feet of this is returned to the atmosphere by evapotranspiration. Most of the streamflows originate in the high forest areas where heavy snowpacks accumulate and evapotranspiration is low. A small amount of runoff originates at the lower altitudes, primarily from infrequent storms. Approximately two-thirds of the runoff is produced from about six percent of the Basin area.

Streamflows fluctuate widely from year to year and season to season because of variations in precipitation, and numerous reservoirs have been constructed to make water available for local needs, exports and downstream obligations. The usable capacity of the Basin reservoirs is about 62 million acre-feet.

WATER COMPACTS

In addition to State laws which provide for intrastate control of water, use of water in the Colorado River system is governed principally by four documents--the Colorado River Compact signed in 1922, the Mexican Water Treaty signed in 1944, the Upper Colorado River Basin Compact signed in 1948 and by the Supreme Court Decree of 1964 in Arizona vs. California.

Among other provisions, the Colorado River Compact apportions to each the Upper and Lower Basin in perpetuity the exclusive beneficial consumptive use of 7,500,000 acre-feet of water of the Colorado River system per annum. It further establishes the obligation of Colorado, New Mexico, Utah, and Wyoming, designated States of the Upper Division, not to cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75 million acre-feet for any period of 10 consecutive years.

The Mexican Water Treaty defines the rights of Mexico to the use of water from the Colorado River system. It guarantees the delivery of 1,500,000 acre-feet of Colorado

River water annually from the United States to Mexico.

In accordance with the Upper Colorado River Basin Compact, Arizona is granted the consumptive use of 50,000 acre-feet of water a year and the other Upper Basin States are each apportioned a percentage of the remaining consumptive use as follows: Colorado 51.75 percent, New Mexico 11.25 percent, Utah 23 percent, and Wyoming 14 percent. Of the first 7,500,000 acre-feet annually of Colorado River water entering the Lower Basin, the States of Arizona and Nevada are apportioned 2,800,000 acre-feet and 300,000 acre-feet respectively. The Lower Division apportionment was divided among the Lower Basin States--Arizona, California, and Nevada--by the decree of the United States Supreme Court in 1964 which states that apportionment was accomplished by the Boulder Canyon Project Act of 1929. If Colorado River mainstem water is available in sufficient quantity to satisfy 7,500,000 acre-feet of annual consumptive use in the three Lower Basin states, Arizona, Nevada, and California are apportioned 2,800,000, 300,000 and 4,400,000 acre-feet, respectively.

WATER USE

There is essentially no outflow from the Basin beyond that required to meet the Mexican Treaty obligation. In 1965, one-half million acre-feet of water was exported out of the Upper Basin for use in other parts of the Upper Basin States. Gross diversions from the Lower Colorado River for use in the southern California service area and the Lower Colorado area in California totaled 5.35 million acre-feet in 1965.

The major use of water within the Basin is for agricultural, municipal, and industrial purposes. At present, over 90 percent of the total Basin withdrawal from ground-water and surface-water sources serves irrigated agriculture within the basin. The remaining portion is used principally for municipal and industrial uses. Approximately three-fourths or 7.0 million acre feet of the water consumptively used in the Basin each year is depleted by agricultural uses. Minor quantities of water are consumed by hydroelectric and thermal power production, recreation, fish and wildlife, rural-domestic needs, and livestock uses. In the urban areas of the Basin, municipal and industrial uses are increasing significantly due to the rapid rate of population growth.

One of the largest causes of streamflow depletions in the Basin is surface evaportation from storage reservoirs. Over 2.0 million acre-feet are estimated to evaporate annually from the lakes and reservoirs of the Basin. Most of this evaporates from major storage reservoirs on the main stem of the Colorado River.

CHAPTER IV. MINERAL QUALITY EVALUATIONS

At the outset of the Project only limited information was available on the causes and sources of salinity in the Colorado River Basin. Little was known about the economic impact of salinity on water uses. No comprehensive evaluation of projected future mineral quality had been made. A major Project effort, therefore, was directed toward improving knowledge in these specific areas. Results of these investigations are summarized in the following sections.

CAUSES OF SALINITY INCREASES

Salinity concentrations progressively increase from the headwaters to the mouth of the Colorado River. This increase results from two basic processes - salt loading and salt concentrating. Salt loading, the addition of mineral salts from various natural and man-made sources, increases salinity by increasing the total salt burden carried by the river. In contrast, salt concentrating effects are produced by streamflow depletions and increase salinity by concentrating the salt burden in a lesser volume of water.

Salt loads are contributed to the river system by natural and man-made sources. Natural sources include diffuse sources such as surface runoff and diffuse ground water discharges, and discrete sources such as mineral springs, seeps, and other identifiable point discharges of saline waters. Man-made sources include municipal and industrial waste discharges and return flows from irrigated lands.

Streamflow depletions contribute significantly to salinity increases. Consumptive use of water for irrigation is responsible for the largest depletions. Consumptive use of water for municipal and industrial purposes accounts for a much smaller depletion. Evaporation from reservoir and stream surfaces also produces large depletions. Phreatophytes, too, cause significant water losses by evapotranspiration, especially in the Lower Basin below Hoover Dam.

Out-of-basin diversions from the Upper Basin contribute significantly to streamflow depletions and produce a salt concentrating effect similar to consumptive use. The water diverted is high in quality and low in salt content. Thus, while these diversions remove substantial quantities of water from the Basin, they remove only a small portion of the salt load.

The relative effects of the various salt loading and salt concentrating factors on salinity concentrations of the Colorado River at Hoover Dam are summarized in Table 1. This evaluation indicates that about 74 percent of average

Table 1. Effect of Various Factors on Salt Concentration of Colorado River at Hoover Dam (1942-61 period of record adjusted to 1960 conditions)a/

Factor	Flow (1,000 AF/Yr)	Cumulative Flow (1,000 AF/Yr)	Salt Load (1,000 Tons/Yr)	Cumulative Salt Load (1,000 Tons/Yr	Cumulative Concentration Tons/AF	Cumulative Concentration mg/l	Change[b/] in Concentration mg/l	% of Total Concentration
Natural Diffuse Sources	14,471	14,471	5,408	5,408	0.374	275	275	39
Natural Point Sources	229	14,700	1,283	6,691	0.455	334	59	8
Irrigation (Salt Contribution)	0	14,700	3,536	10,227	0.696	512	178	26
Irrigation (Consumptive Use)	-1,883	12,817	0	10 227	0.798	587	75	11
Municipal & Industrial Sources	-42	12,775	146	10,373	0.812	597	10	1
Exports Out of Basin	-465	12,310	-37	10,336	0.840	617	20	3
Evaporation & Phreatohytes	-1,409	10,901	0	10,336	0.948	697	80	12

Storage Release from Hoover	412	11,313	391	10,727	0.948	697	0	0
Total		11,313		10,727		697		100

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a/ Based on data from:
(1) USGS, Prof. Paper 441, "Water Resources of the Upper Colorado River Basin, Technical Report," 1965.
(2) USDI, Progress Report No. 3, "Quality of Water, Colorado River Basin," January 1967.
(3) FWQA unpublished Records.

b/ Concentrations in this column will vary depending upon the order in which they are calculated.

salinity concentrations for the 20-year period 1942-1961 were attributable to salt loading factors. The remaining 26 percent were attributable to salt concentrating factors. The relative effects of natural and man-made factors are also summarized in Table 1. Only about 47 percent of average salinity concentrations for the 20-year period were attributed to natural factors. This evaluation indicates that salinity concentrations would have averaged only 334 mg/l at the Hoover Dam location under natural conditions for the 1942-1961 period.

A more detailed discussion of the various factors affecting salt concentrations is contained in Appendix A.

SOURCES OF SALT LOADS

Natural sources, including both diffuse and discrete sources, are the most important sources of salt loads in the Colorado River Basin. They contribute about two-thirds of the average annual salt load passing Hoover Dam. Natural diffuse pickup of mineral salts by surface runoff and groundwater inflow takes place throughout the Colorado River Basin; however, the areas responsible for the greatest salt loads are located in the Upper Basin. Several relatively small areas, such as Paradox Valley, have very high rates of pickup and contribute large salt loads. Diffuse sources contribute about half of the Basin salt burden.

Discrete or point salinity sources also occur throughout the Basin. In the Lower Basin, mineral springs add more salt to the Colorado River than any other type of salinity source. Blue Springs, located near the mouth of the Little Colorado River, contributes a salt load of about 547,000 tons per year, or approximately five percent of the annual salt burden at Hoover Dam. Blue Springs is the largest point source of salinity in the entire Colorado River Basin. In the Upper Basin, some 30 significant mineral springs have been identified. Dotsero and Glenwood Springs, two major point sources of salinity, contribute a salt load of about 518,000 tons per year.

Man's use of water for irrigation, municipal, and industrial purposes contributes to salt loading effects. Irrigation is the major man-made source of salinity throughout the Basin. The annual salt pickup from all irrigation above Hoover Dam averages about two tons per acre. For some areas, especially those underlain by shales and saline lake-bed formations, salt pickup is much higher, with average annual loads ranging between four and eight tons per acre. Below Hoover Dam, the average annual salt pickup from irrigation is about 0.5 ton per acre after the initial leaching period.

Municipal and industrial salinity sources located within the drainage area of Lake Mead contribute only about one percent of the average annual salt load at Hoover Dam. Below Hoover Dam, these sources are responsible for less than one percent of the average annual salt load.

The sources and amounts of salt loads for the Upper Basin, the Lower Basin, and the drainage area of Lake Mead above Hoover Dam are summarized in Table 2. Data presented in Table is based on salinity conditions existing in the period 1963-1966 and should not be confused with data in Table 1 which is based on period 1942-61. The Upper Basin sources contribute approximately 77 percent of the salt load at Hoover Dam, about three-fourths of total Basin salt load.

A detailed discussion of the nature, location, and magnitude of salt sources in the Basin is contained in Appendix A.

Table 2. Summary of Salt Load Distributions

	Salt Load (1,000) T/Yr.			Percent of Total Load		
Source	Upper Basin	Lower Basin	Above Hoover Dam	Upper Basin	Lower Basin	Above Hoover Dam
Natural Diffuse Sources	4,400	1,400	5,760	52.2	52.1	53.7
Natural Point Sources	510	770	1,280	6.1	28.6	11.9
Irrigation	3,460	420	3,540	41.1	15.6	33.0
Municipal and Industrial	50	100	150	0.6	3.7	1.4
Total	8,420	2,690	10,730	100.0	100.0	100.0

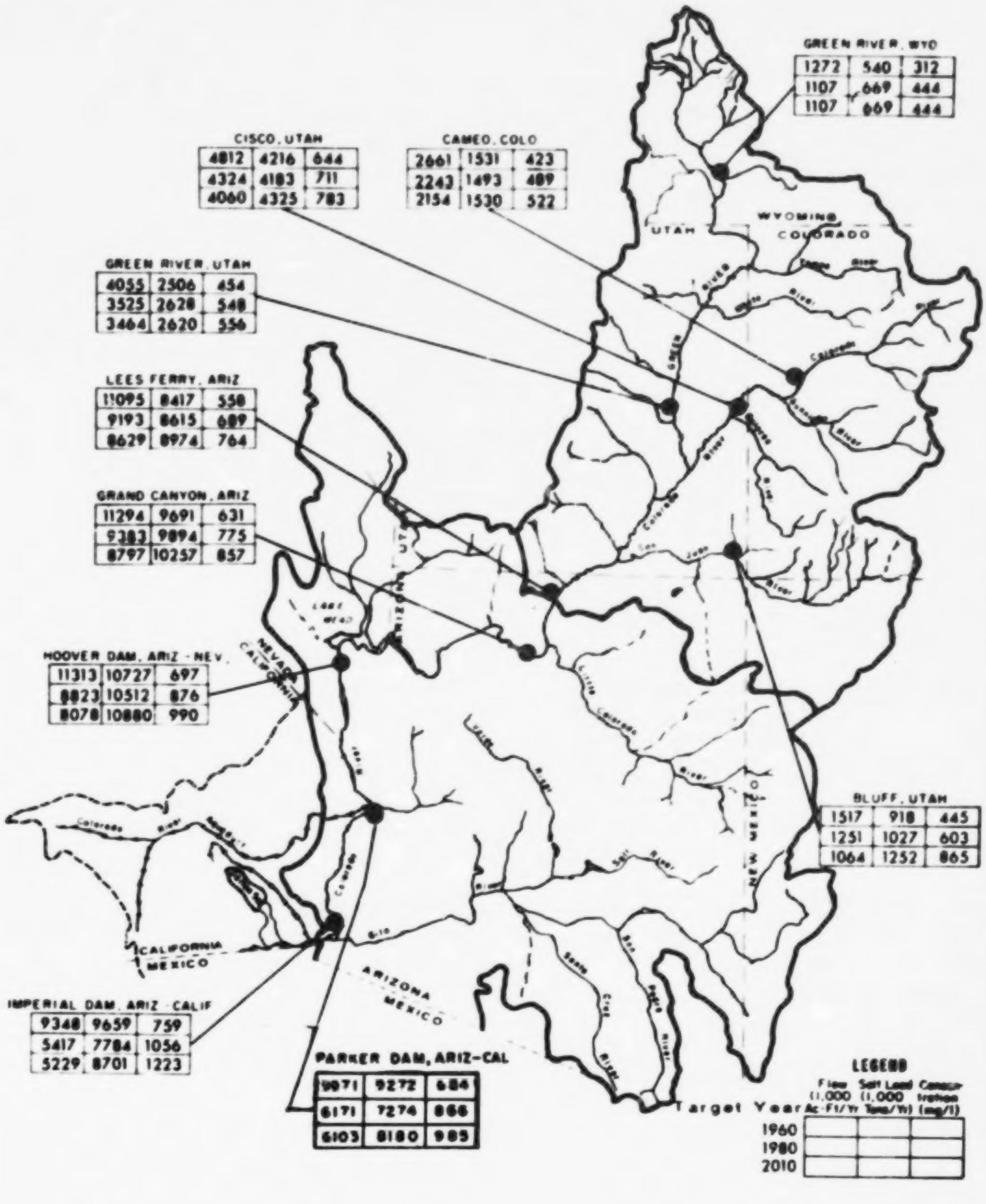
PRESENT AND FUTURE SALINITY CONCENTRATIONS

Long-term average salinity levels have progressively increased in the Colorado River system as the Basin's water resources have been developed and consumptive use of water for various purposes has increased. This trend is expected to continue with future water resource development and to bring about serious water quality implications. As the economic impact of salinity is closely related to the rate at which salinity levels rise in the future, an evaluation was made of present and future salinity concentrations in the Basin to provide the basis for the economic evaluation discussed in the following section. Historical salinity and stream flow data for the 1942-1961 period of hydrologic record were used as the basis for estimating average salinity concentrations under various conditions of water development and use. This historical data was modified to reflect the effects that water uses existing in 1960 would have had on average salinity levels if these uses had existed during the full 20-year period. Average salinity concentrations obtained from this modified data were designated as 1960 base conditions. These concentrations are shown at key Basin locations in Figure 2.

Predicted future conditions of water use, based on Federal, State and local development plans available in 1967, were utilized to develop detailed projections of 1980 and 2010 salinity levels. These projections based on the assumptions that water resource development would proceed as planned in 1967 and that the 1942-1961 hydrologic record would be repeated, are shown at key Basin locations in Figure 2. These projections are for long-term average salinity concentrations; actual concentrations can be expected to fluctuate about these averages as a result of seasonal changes in streamflow and other hydrological factors. Sensitivity of future salinity projections to the period of record utilized and the assumptions concerning the rate of water resource development are discussed in Appendix C.

To provide the degree of refinement necessary to allow evaluation of the small incremental changes in salinity levels produced by a given water resource development, salinity concentrations were computed to the nearest mg/l in making the projections shown in Figure 2. It was not intended that a high degree of accuracy by implied as salinity projections are dependent upon a number of factors which are not known with certainty.

The detailed salinity projections presented in Figure 2 were made on the basis that no limits would be placed on future water resource developments other than those limits imposed by availability of a water supply under applicable water laws. In evaluating potential means of managing salinity on a basinwide basis as discussed in Chapter VII, it became apparent that one possible approach to management of future salinity levels would be to limit further water resource development in the Basin. A second set of salinity projections was made to evaluate the results of limiting such development. A comparison of future salinity levels at four key locations on the Lower Colorado River for unlimited and limited development conditions is shown in Table 3.


GREEN RIVER, WYO
1272 | 540 | 312
1107 | 669 | 444
1107 | 669 | 444
CISCO, UTAH
4812 | 4216 | 644
4324 | 4183 | 711
4060 | 4325 | 783
CAMEO, COLO
2661 | 1531 | 423
2243 | 1493 | 489
2154 | 1530 | 522
GREEN RIVER, UTAH
4055 | 2506 | 454
3525 | 2628 | 548
3464 | 2620 | 556
LEES FERRY, ARIZ
11095 | 8417 | 558
9193 | 8615 | 689
8629 | 8974 | 764
GRAND CANYON, ARIZ
11294 | 9691 | 631
9383 | 9894 | 775
8797 | 10257 | 857
HOOVER DAM, ARIZ - NEV.
11313 | 10727 | 697
8823 | 10512 | 876
8078 | 10880 | 990
BLUFF, UTAH
1517 | 918 | 445
1251 | 1027 | 603
1064 | 1252 | 865
IMPERIAL DAM, ARIZ - CALIF
9348 | 9659 | 759
5417 | 7784 | 1056
5229 | 8701 | 1223
PARKER DAM, ARIZ-CAL
9071 | 9272 | 684
6171 | 7274 | 866
6103 | 8180 | 985
WYOMING
COLORADO
UTAH
ARIZONA
NEVADA
CALIFORNIA
NEW MEXICO
CALIFORNIA
MEXICO
ARIZONA
MEXICO
Green River
Colorado River
Lake Mead
Little Colorado River
Gila
LEGEND
Target Year
Flow (1,000 Ac-Ft/Yr)
Salt Load (1,000 Tons/Yr)
Concentration (mg/l)
1960
1980
2010

NOTE : Values shown are based on 1942 – 1961 period of record modified to 1960 conditions.

Figure 2. Flow, Loads, & Salinity Concentrations in Streams in the Colorado River Basin

Table 3. Comparison of Salinity Projections

	Unlimited Development Conditions			Limited Development Conditions	
Location	1960 Base	1980	2010	1970	1980 & 2010
Hoover Dam	697	876	990	760	800
Parker Dam	684	866	985	760	800
Palo Verde Dam	713	940	1082	800	850
Imperial Dam	759	1056	1223	865	920

Salinity projections for 1970 conditions of limited development were made on the basis that water resource developments currently in operation and present water use patterns would hold for a repetition of the 1942-1961 hydrological record. The 1970 projections reflect the effects of evaporation losses from Lake Powell operated at normal levels. Since Lake Powell has not yet reached normal storage levels, evaporation losses are less than expected average losses and present average salinity levels at downstream points are correspondingly lower than projected.

For 1980 conditions of limited development, it was assumed that no new water resource developments would be placed in operation but that those projects currently under construction would be completed as planned. It was assumed that all such construction could be completed by 1980 and that 2010 conditions of water use would remain the same as for 1980.

In the past, salt loading was the dominant factor affecting salinity concentrations, contributing about three-fourths of average salinity concentrations at Hoover Dam under 1960 conditions. In contrast, future increases in salinity levels will result primarily from flow depletions caused by out-of-basin exports, reservoir evaporation and consumptive use of water for municipal, industrial and agricultural purposes. The relative effects of these factors on future salinity concentrations at Hoover Dam are summarized in Table 4.

Projections for Hoover Dam indicate a relatively constant, average salt load over the next 40 years, but a substantial drop in water flow. Over 80 percent of the future increase in salinity concentrations at Hoover Dam will be the result of increases in flow depletions. Over three-fourths of the projected salinity increase between 1960 and 2010 will be the result of increases in reservoir evaporation brought about by the filling of major storage reservoirs completed since 1960 and of increases in consumptive use brought about by the expansion of irrigated agriculture.

Table 4 Effect of Various Factors on Future Salt Concentration of Colorado River at Hoover Dam (1942-61 period of record adjusted to 2010 conditions)a/

Factor	Flow (1,000 AF/Yr)	Cumulative Flow (1,000 AF/Yr)	Salt Load (1,000 Tons/Yr)	Cumulative Salt Load (1,000 Tons/Yr	Cumulative Concentration Tons/AF	Cumulative Concentration mg/l	Change b/ in Concentration mg/l	% of Total Concentration
Natural Diffuse Sources	14,471	14,471	5,408	5,408	0.374	275	275	28
Natural Point Sources	229	14,700	1,283	6,691	0.455	334	59	6
Irrigation (Salt Contribution)	--	14,700	4,225	10,916	0.743	546	212	21
Irrigation (Consumptive Use)	-2,905	11,795	--	10,916	0.925	680	134	14
Municipal & Industrial Sources	-427	11,368	165	11,081	0.975	717	37	4
Exports Out of Basin	-1,174	10,194	-140	10,941	1.073	789	72	7

Reservoir Evaporation	-2,041	8,153	0	10,941	1.342	986	197	20
Model Adjustments	-75	8,078	-61	10,880	1.347	990	4	--
Total		8,078		10,880		990		100

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a/ Based on data from:
(1) USGS, Prof. Paper 441, "Water Resources of the Upper Colorado River Basin, Technical Report," 1965
(2) USDI, Progress Report No. 3, "Quality of Water, Colorado River Basin," January 1967.
(3) FWPCA unpublished records.

b/ Concentrations in this column will vary depending upon the order in which they are calculated.

PHYSICAL AND ECONOMIC IMPACT OF SALINITY

Water uses exhibit an increasing sensitivity to rising salinity concentrations. As concentrations of salinity rise water use is progressively impaired, and at some critical level, defined as a threshold level, utilization of the supply is no longer possible. In the Colorado River Basin, future salinity concentrations will be below threshold levels for in stream uses such as recreation, hydroelectric power generation, and propagation of aquatic life. Only marginal impairment of these uses is anticipated.

In the Lower Colorado River present salinity concentrations are above threshold limits for municipal, industrial and agricultural uses. Some impairment of these uses is now occurring and future increases in salinity will increase this adverse impact. The Projects investigated this progressive impairment of water uses and developed methods to quantify the resulting economic impact on both water users and the regional economy. It should be emphasized that the methodology employed by the Project staff was intentionally conservative; all costs developed by this report to describe the impact of salinity must be considered minimal values.

Initial investigations conducted on the potential impact of future salinity levels revealed that only small effects on water uses could be anticipated in the Upper Basin. Subsequent investigations, therefore, were limited to three main study areas: the Lower Main Stem and Gila areas in the Lower Basin, and the Southern California area encompassing the southern California water service area. The boundaries of these study areas follow political rather than hydrological boundaries and are shown in Figure 3. Although significant economic effects are known to occur in Mexico, lack of data precluded their inclusion.

Effects of Salinity on Beneficial Uses of Water

Initial evaluations of possible salinity effects on Basin water uses indicated that adverse physical effects would essentially be limited to municipal, industrial, and agricultural uses. Major effects on these uses are discussed briefly in this section.

Domestic uses comprise the major utilization of municipal water supplies. Total hardness, a parameter closely related to salinity, is of primary interest in assessing water quality effects on these uses. Increases in the concentration of hardness lead to added soap and detergent

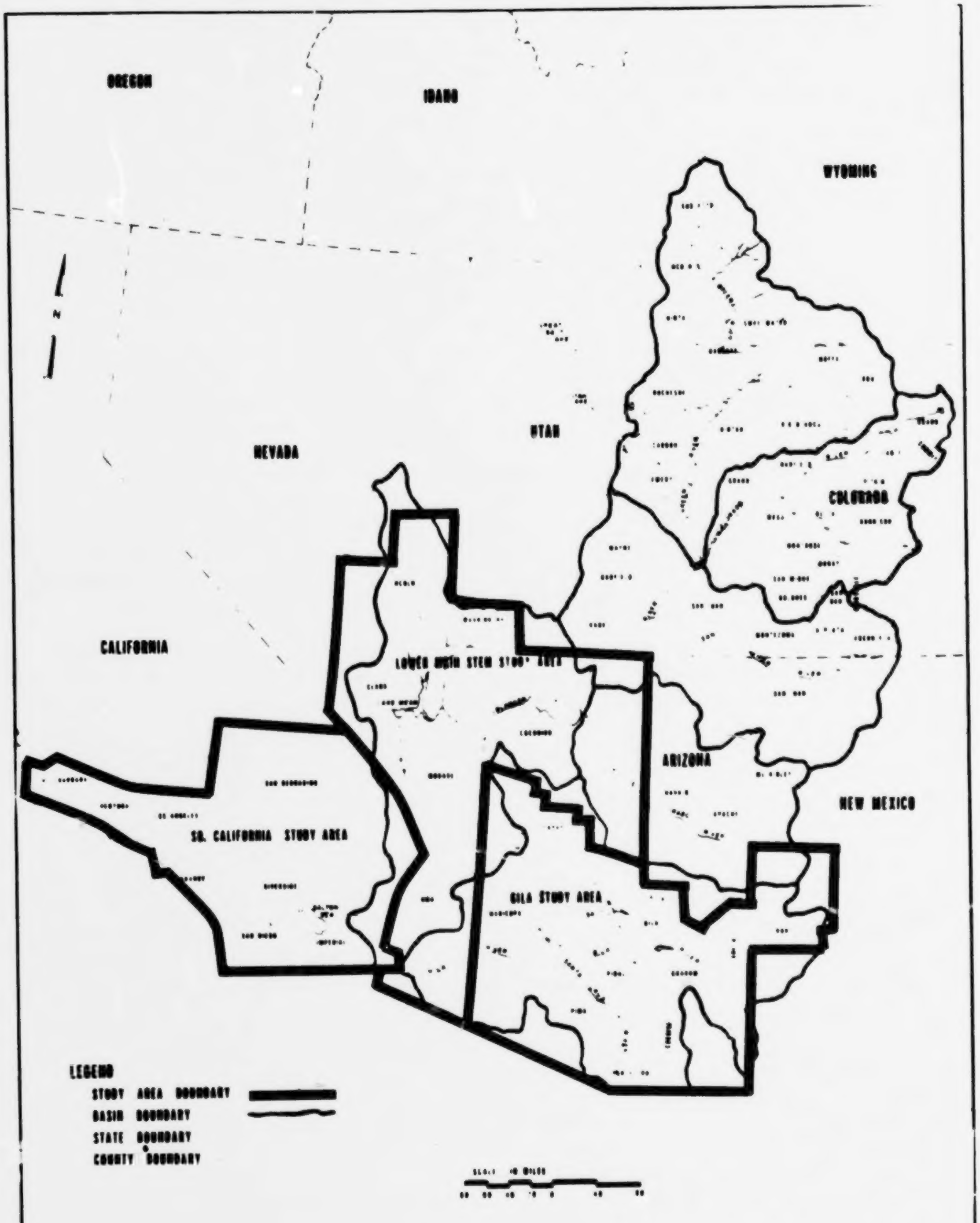
OREGON
IDAHO
WYOMING
NEVADA
UTAH
COLORADO
CALIFORNIA
LOWER MAIN STEM STUDY AREA
ARIZONA
NEW MEXICO
SO. CALIFORNIA STUDY AREA
GILA STUDY AREA
LEGEND
STUDY AREA BOUNDARY
BASIN BOUNDARY
STATE BOUNDARY
COUNTY BOUNDARY
N

Figure 3. Location of Salinity Impact Study Areas

consumption, corrosion and scaling of metal water pipes and water heaters, accelerated fabric wear, added water softening costs, and in extreme cases, abandonment of a supply. By most hardness measures, raw water supplies derived from the Colorado River at or below Lake Mead would be classified as very hard.

Boiler feed and cooling water comprise a major portion of water used by industry in the Basin. Mineral quality of boiler feed water is an important factor in the rate of scale formation on heating surfaces, degree of corrosion in the system, and quality of produced steam. In cooling water systems, resistance to slime formation and corrosion are effected by mineral quality. The required mineral quality levels are maintained in boiler and cooling systems by periodically adding an amount of relatively good quality water (make-up water) and discharging from the system an equal volume of the poorer quality water (blowdown).

Salinity effects on agricultural uses are manifested primarily by limitations on the types of crops that may be irrigated with a given water supply and by reductions of crop yields as salinity levels increase. Other conditions being equal, as salinity levels increase in applied irrigation water, salinity levels in the root zone of the soil also increase.

Because different crops have different tolerances to salts in the root zone, limits are placed on the types of crops that may be grown. When salinity levels in the soil increase above the threshold levels of a crop, progressive impairment of the crop yield results. Irrigation water which has a high percentage of sodium ions may also affect soil structure and cause adverse effects on crop production. The primary means of combating detrimental salinity concentrations in the soil are to switch to salt tolerant crops or to apply more irrigation water and leach out excess salts from the soil.

Direct Economic Effects Upon Water Users

The previously described physical impacts of salinity upon consumptive uses of water were translated into economic values by evaluating how each user might alleviate the effects of salinity increases. Municipalities could (1) do nothing and the residents would consume more soap and detergents or purchase home softening units; (2) build central water softening plants; or (3) develop new, less mineralized water supplies. Industrial users could combine more extensive treatment of their water supply with the purchase of additional make-up water based upon the economics of prevailing conditions. The alternatives available to irrigation water users are governed by the availability of additional water. (1) If the irrigator does nothing, he will suffer economic loss from decreased crop yields. (2) If additional water is available, root zone salinity may be reduced by increasing leaching water applications. The irrigator would incur increased costs for purchase of water, for additional labor for water application, and for increased application of fertilizer to replace the fertilizer leached out. (3) If no additional water is available, the irrigator can increase the leaching of salts from the soil by applying the same amount of water to lesser acreage. This, of course, results in an economic loss since fewer crops can be grown. (4) The last alternative is to plant salt tolerant crops. An economic loss would usually occur since salt tolerant crops primarily produce a lower economic return.

The cost of applying each of the alternative remedial actions was determined, and the least costly alternative selected for subsequent analyses. The yield-decrement method, which measures reductions in crop yield resulting from salinity increases, was selected to evaluate the economic impact on irrigated agriculture. For industrial use, an estimate of required make-up water associated with salinity increases was selected to calculate the penalty cost. Municipal damages were estimated by calculating the required additional soap and detergents needed. Details of the methodology employed and a discussion of the assumptions required to complete the analysis are presented in Chapter IV of Appendix B.

The direct economic costs of mineral quality degradation may be summarized in two basic forms, total direct costs and penalty costs. Total direct costs incurred for a given salinity level result from increases in salinity concentrations above the threshold levels of water uses. Penalty costs are the differences between total direct costs for a given salinity level and for a specified base level. They represent the marginal costs of increases in salinity concentrations above base conditions.

Detailed economic studies were aimed at evaluating penalty costs in order to provide a basis for assessing the economic impact of predicted future increases in salinity. Water quality, water use patterns, and economic conditions existing in 1960 were selected as base conditions. Water use and economic conditions projected for the target years 1980 and 2010 and predictions of future salinity concentrations were utilized to estimate total direct costs in the future. Direct penalty costs were then computed from differences in total direct costs. These direct penalty costs are summarized by type of water use and by study area in Table 5. The indirect and total penalty costs, also presented in the table, are discussed below.

Indirect Economic Effects

Because of the interdependence of numerous economic activities, there are indirect effects on the regional economy stemming from the direct economic impact of salinity upon water users. These effects, termed indirect penalty costs, can be determined if the interdependency of economic activities are known.

The Project's economic base study investigated the interdependence of various categories of economic activity or sectors. These interdependent relationships, in the form of transactions tables, were quantified for 1960 conditions, and were projected for the target years 1980 and 2010. A digital computer program known as an "input-output model" was developed to follow changes affecting any given industry through a chain of transactions in order to identify secondary or indirect effects on the economy stemming from the direct economic costs of salinity. Application of the model to evaluate indirect penalty costs is discussed in Appendix B, Chapter V. The indirect penalty costs predicted by the model are summarized in Table 5.

Total Penalty Costs

Total penalty costs represent the total marginal costs of increases in salinity concentrations above base conditions. They are the sum of direct penalty costs incurred by water users and indirect penalty costs suffered by the regional economy. Total penalty costs are also summarized in Table 5.

Several conclusions can be drawn from Table 5.

1. The majority of the penalty costs (an average of 82 percent) will result from water use for irrigated agriculture. This fact may be attributed to the heavy utilization of Colorado River water for irrigation along the Lower Colorado River and in the southern California area.

2. Over three-fourths of the penalty costs will be incurred in the southern California water service area. These costs will result primarily from agricultural use in the Imperial and Coachella Valleys, and municipal and industrial uses in the coastal metropolitan areas.

Table 5 Summary of Penalty Costs

Location and Water Use	1980 Direct Penalty Cost	1980 Indirect Penalty Cost	1980 Total Penalty Cost	2010 Direct Penalty Cost	2010 Indirect Penalty Cost	2010 Total Penalty Cost
		($1,000 Annually)*			($1,000 Annually)*	
Lower Main Stem Study Area						
Irrigation Agriculture	1,096	765	1,861	2,424	2,237	4,661
Industrial	107	4	111	410	15	425
Municipal	275	14	289	779	39	818
Sub-Total	1,478	783	2,261	3,613	2,291	5,904
Southern California Study Area						
Irrigated Agriculture	4,617	2,447	7,064	10,072	6,195	16,267
Industrial	56	3	59	103	5	108
Municipal	1,347	305	1,652	2,239	507	2,746
Sub-Total	6,020	2,755	8,775	12,414	6,707	19,121
Gila Study Area						
Irrigated Agriculture	---	---	---	246	125	371
Industrial	---	---	---	---	---	---
Municipal	---	---	---	---	---	---
Sub-Total	---	---	---	246	125	371
Total	7,498	3,538	11,036	16,273	9,123	25,396

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* - 1960 Dollars

3. Penalty costs in the Gila study area will be minor and will not occur until after 1980 when water deliveries to the Central Arizona Project begin. (It was assumed that all Central Arizona Project water would be utilized for agricultural purposes.)

It should be noted that the penalty costs summarized in Table 3 do not represent the total economic impact of salinity, but only the incremental increases in salinity detriments resulting from rising salinity levels. There are economic costs known as salinity detriments that were being incurred by water users in 1960 as a result of salinity levels exceeding threshold levels for certain water uses. These costs would continue in the future if salinity levels remained at the 1960 base conditions. Total salinity detriments are discussed below.

Total Salinity Detriments

The detailed economic analysis outlined in previous sections and discussed in detail in Appendix B forms a basis for evaluating the distribution of the total economic impact of future salinity increases. Penalty costs are not practical, however, for evaluation of the economic impact of basinwide salinity control, especially when reductions in salinity concentrations below 1960 base levels were considered. For this reason, estimates of total salinity detriments were prepared utilizing the basic information developed for peanlty cost evaluations. These estimates, in the form of empirical relationships between salinity levels at Hoover Dam and salinity detriments, are shown graphically for various target years in Figure 4.

Hoover Dam is a key point on the Colorado River system. Water quality at most points of use in the Lower Basin and Southern California water service area may be directly related to salinity levels at Hoover Dam. Modifications of salt loads contributed by sources located upstream from Hoover Dam also directly affect salinity levels at this location. Salinity concentrations at Hoover Dam were, therefore, utilized as a water quality index to which all economic evaluations were keyed.

Total salinity detriments are the sum of direct costs to water users (including direct penalty costs) and indirect penalty costs. A discussion of the methodology used to develop the detriment relationships is contained in Appendix C. It should be noted that the salinity detriments are expressed in terms of 1970 dollars. It was necessary to modify the basic data utilized in evaluating penalty costs (expressed in terms of 1960 dollars) in order to make the

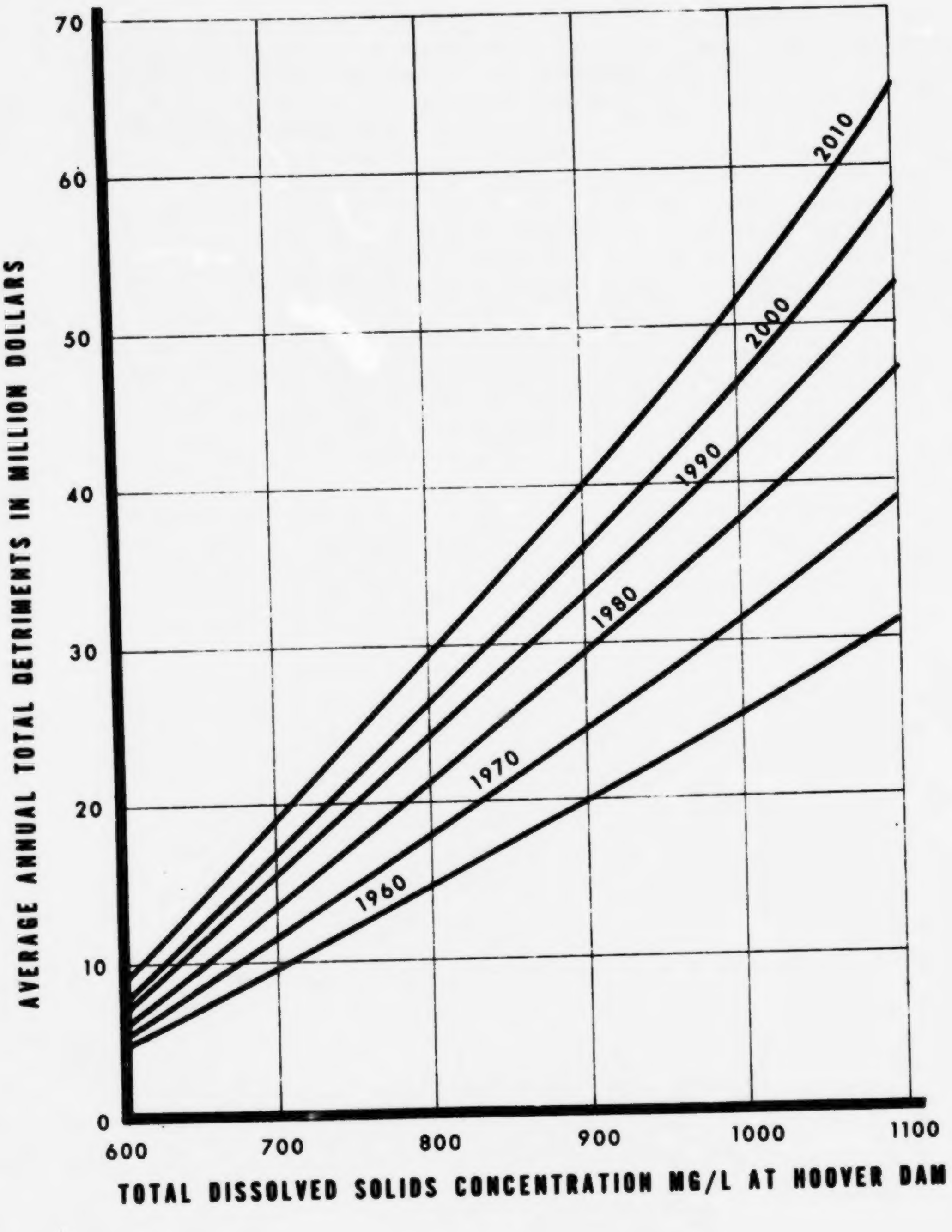

Figure 4. Salinity Detriments

salinity detriments compatible with current estimates of salinity management costs discussed in Chapter VII.

Using the projected salinity levels for Hoover Dam shown in Table 3 and the salinity detriment functions of Figure 4, it is possible to compare the total economic detriments of salinity under various conditions of water use and resource development. Under 1960 conditions, the annual economic impact of salinity was estimated to total $9.5 million. It is estimated that present salinity detriments have increased to an annual total of $15.5 million. If water resources development proceeds as proposed and no salinity controls are implemented, it is estimated that average annual economic detriments (1970 dollars) would increase to $27.7 million in 1980 and $50.5 million in 2010. If future water resources development is limited to those projects now under construction, estimated annual economic detriments would increase to $21 million in 1980 and $29 million in 2010.

CHAPTER V. TECHNICAL POSSIBILITIES FOR SALINITY CONTROL

Technical possibilities for minimizing and controlling salinity in the Colorado River Basin may be divided into two categories: water-phase and salt-phase control measures. Water-phase measures seek to reduce salinity concentrations by augmenting the water supply, while salt-phase measures seek to reduce salt input into the river system. Specific control measures are listed in Table 6 and are discussed at length in Appendix C, Chapter III.

Various factors, such as economic feasibility, lack of research and legal and institutional constraints limit the present application of some water-phase and salt-phase control measures. The most practical means of augmenting the Basin water supply include importing water from other basins, importing demineralized sea water, and utilizing weather modification techniques to increase precipitation and runoff within the Basin. Practical means of reducing salt loads include: impoundment and evaporation of point source discharges, diversion of runoff and streams around areas of salt pickup, improvement of irrigation and drainage practices, improvement of irrigation conveyance facilities, desalination of saline discharges from natural and man-made sources, and desalination of water supplies at points of use. These measures could be implemented in a variety of locations and in several different combinations.

Table 6. Technical Possibilities for Salinity Control

I. Measures for Increasing Water Supply

  A. Water Conservation Measures

    1. Increased Watershed Runoff
    2. Suppression of Evaporation
    3. Phreatophyte Control
    4. Optimized Water Utilization for Irrigation
      a. Reduced Consumptive Use
      b. Improved Irrigation Efficiency
    5. Water Reuse

  B. Water Augmentation Measures

    1. Weather Modification
    2. Water Importation
      a. Fresh Water Sources
      b. Demineralized Sea Water

Table 6. Technical Possiblities for Salinity Control (con't)

II. Measures for Reducing Salt Loading

    A. Control of Natural Sources

        1. Natural Discrete Sources
            a. Evaporation of Discharge
            b. Injection into Deep Geological Formations
            c. Desalination
            d. Suppression of Discharge
            e. Reduction of Recharge
        2. Natural Diffuse Sources
            a. Surface Diversions
            b. Reduced Groundwater Recharge
            c. Reduced Sediment Production

    B. Control of Man-Made Sources

        1. Municipal and Industrial Sources
            a. Evaporation
            b. Injection into Deep Geological Formations
            c. Desalination
        2. Irrigation Return Flows
            a. Proper Land Selection
            b. Canal Lining
            c. Improved Irrigation Efficiency
            d. Proper Drainage
            e. Treatment or Disposal of Return Flows

CHAPTER VI. SALINITY CONTROL ACTIVITIES

Activities related to the control and management of salinity have been carried out over the years by a variety of agencies and institutions and have contributed to the overall knowledge of salinity control technology. In the past four years, several activities have been specifically directed toward the application of salinity control technology to the Colorado River Basin. The current status of these activities is discussed in the following sections.

TECHNICAL INVESTIGATIONS

Limited investigations of several potential salinity control projects and control measures were made by the Project. These investigations evaluated a number of technical possibilities for salinity control discussed in Chapter V. Salinity control research needs were also identified; these provided the basis for support by the FWQA of several research efforts discussed below.

Early in FY 1968, the FWQA and the Bureau of Reclamation initiated a cooperative salinity control reconnaissance study in the Upper Basin. Study objectives were to identify controllable sources of salinity and to determine technically feasible control measures and estimate their costs. A shortage of funds resulted in discontinuance of the study during FY 1970. A report entitled "Cooperative Salinity Control Reconnaissance Study, Upper Colorado River Basin," presenting the results of the study to date, is scheduled for release during 1970.

During the course of the study, preliminary plans were developed for two salinity control projects, and cost estimates were prepared for a number of control measures. (1) A project was formulated to eliminate the heavy pickup of salt by the Dolores River as it crosses a salt anticline in the Paradox Valley of western Colorado. Control of this salt source could be achieved by constructing both a floodwater retarding dam and a lined channel to convey the river across the valley and prevent recharge of an aquifer in contact with salt formations. (2) A project was also formulated to control the salt load from Crystal Geyser, an abandoned oil test well which periodically discharges highly mineralized water. Control could be achieved by collecting the discharge and pumping it to a lined impoundment for evaporation. If suitable land area for an evaporation pond could be found and evaporation rates were high enough, a project of this type could be potentially applicable for control of some of the more concentrated mineral springs.

Cost estimates were prepared for several types of salinity control measures, but preliminary plans were not developed for specific sites. For control of irrigation return flows, the costs of impounding and evaporating the flows at two topographically different sites were estimated. The costs of deep well injection of relatively small quantities of the more concentrated return flows were also evaluated. The cost of lining canals and distribution systems in several existing irrigation projects was investigated.

Following discontinuance of the cooperative study, the project conducted a preliminary study of a project to control the salt load from several large mineral spring areas in the vicinity of Glenwood Springs, Colorado.

A similar preliminary study of control measures for LaVerkin Springs, a large thermal spring discharging significant quantities of radium-226 and mineral salts into the Virgin River of southern Utah, is currently underway.

RESEARCH AND DEMONSTRATION ACTIVITIES

A number of research and demonstration projects presently underway are expected to contribute significantly to the development and/or evaluation of various salinity control measures.

(1) Under an FWQA research grant, a project entitled "Quality of Irrigation Return Flow" was initiated during FY 1969 by Utah State University at Logan, Utah. This project is directed toward the dual objectives of increasing the store of knowledge of basic processes controlling the movement of salts in soils, and applying this knowledge to development of salinity control measures. Research to date has primarily been conducted on a small scale in the laboratory and in greenhouse lysimeters. A digital simulation model is being developed to accurately predict the movement of salts and the changes in quality of applied irrigation water within the soil and root zone. This model will be utilized to design on-farm irrigation practices, such as the rate and timing of irrigation applications, which will minimize the salt load contributed by irrigation activities.

The University has established a 40-acre test farm in Ashley Valley near Vernal, Utah, and will conduct full scale field testing of theoretical results during 1970 and 1971. Establishment of a test farm at this location will provide a demonstration of salinity control measures under conditions similar to those found in many irrigated areas of the Upper Basin.

(2) In response to a request from the FWQA, a large scale research project entitled "Prediction of Mineral Quality of Return Flow Water from Irrigated Land" was initiated by the Bureau of Reclamation in late FY 1969, with financial support provided by the FWQA. The primary objective of this project is to develop a digital simulation model that will accurately predict the quantity and quality of irrigation return flows from an entire irrigation project with known soil, groundwater, and geologic and hydrologic characteristics. Such a model would have several applications. The water quality impact of a proposed irrigation development could be more accurately assessed. More importantly, the model could be utilized to evaluate the water quality effects of alternative project designs and, therefore, allow selection of the optimal design of features in order to minimize any adverse effects on water quality. Another application would be to evaluate improvements of irrigation facilities and practices in established irrigated areas aimed at reducing presently high salt contributions.

Field studies will be conducted in several locations with various soil and geologic conditions in order to verify prediction techniques under a wide range of conditions. Ashley Valley, surrounding Vernal, Utah, was selected as the initial study area. Characterization studies of this area are currently underway. Using present data, initial runs of an elementary simulation model will be made during 1970. The model will be refined; additional data will be collected during the next three years; and field studies at other locations will be initiated.

(3) The "Grand Valley Salinity Control Demonstration Project" at Grand Junction, Colorado, was initiated in FY 1969 under a FWQA demonstration grant. Its objective is to demonstrate the salinity control potential of lining irrigation canals and laterals. The Grand Valley is underlain by an aquifer containing highly saline groundwater. Seepage from canals and laterals contributes to recharge of this aquifer and displaces the saline groundwater into the Colorado River, thereby increasing its salt load. Reduction of such recharge by reducing seepage from conveyance systems, is therefore, expected to reduce the salt load discharged to the river.

A major portion of the canals and some of the laterals serving a study area of about 4,600 acres have been lined and additional lining will be completed during the 1970-1971 winter season. A simulation model is being developed which will evaluate the effects of changes in irrigation efficiency on salt load contributions, as well as changes in seepage losses from the conveyance system. Upon completion this model will not only allow the results of the demonstration project to be projected valley-wide, but also form the basis for future salinity control activities in Grand Valley. Completion of the demonstration project, including all post-construction studies, is scheduled for mid-1972.

(4) Only limited research efforts are presently directed toward defining processes to control salt loading from natural sources. The FWQA provided financial support to Utah State University for one such effort, "The Electric Analog Simulation of the Salinity Flow System within the Upper Colorado River Basin." Results from this research provided new information concerning the distribution of salt sources in the Upper Basin and will serve as a potential analytical tool for evaluating the water quality effects of various salinity control measures. The final research report is scheduled for publication during 1970.

(5) In late 1969 a research project entitled "Effect of Water Management on Quality of Groundwater and Surface Recharge in Las Vegas Valley," was initiated by Desert Research Institute, Las Vegas, Nevada, under a FWQA research grant. Among other things this project will evaluate the movement of salts in the groundwater system and the exchange of salts between the groundwater and surface waters of Las Vegas Wash. Research results will help define the optimum approach for control of this salt source. Completion of the research effort is scheduled for mid-1973.

(6) A cooperative regional research effort, "Project W-107, Management of Salt Load in Irrigation Agriculture," was initiated in 1969 by seven western universities and the U. S. Salinity Laboratory of the Agricultural Research Service. Work currently underway or planned, covers a wide range of salinity management aspects and should provide a number of results which can be applied to Basin salinity problems. The FWQA is participating in the coordination of this research effort.

SALINITY CONTROL PROJECTS

During the latter part of FY 1968, the FWQA made funds available and requested the Bureau of Reclamation to select a pilot project to test and demonstrate control methods for reducing salinity concentrations and salt loads in the Colorado River system. The plugging of two flowing wells, the Meeker and Piceance Creek wells near Meeker, Colorado, was selected as the pilot demonstration project. Completion of the well plugging in August, 1968 reduced the salinity load of the White River and the Colorado River system by about 62,500 tons annually. This is approximately 19 percent of the average annual salinity load in the White River near Watson, Utah. Plugging the Meeker and Piceance Creek wells initially decreased the annual flow of the White River by about 2,380 acre-feet. In the opinion of the Bureau's regional geologist, however, this flow will reappear through natural springs nearer the recharge area at an improved quality, and plugging the wells will not decrease the annual flow of the White River. Costs for plugging the two wells totaled about $40,000.

Another flowing well near Rock Springs, Wyoming, which contributed approximately 5,000 tons of salt annually, was plugged in November 1968, under the direction of the Wyoming State Engineer. The effects of eliminating this salt source have not been evaluated.

In late 1969, the Utah Oil and Gas Commission plugged seven abandoned oil test wells near Moab, Utah, including two flowing wells which formerly contributed a salt load of approximately 33,000 tons per year to the Colorado River. Costs of plugging the wells totaled about $35,000.

It is estimated that plugging the five flowing wells in Colorado, Wyoming, and Utah will reduce the average annual salt load passing Hoover Dam by 100,000 tons or 0.93 percent. Under present conditions this salt load reduction would reduce average salinity concentrations by about 6 mg/l. Although this change in salinity concentrations is small when compared to present salinity levels, the resulting economic benefits are significant. These benefits are estimated to range annually from $0.4 million in 1970 to $1.0 million in 2010 and have a present worth of more than $10 million.

CHAPTER VII. ALTERNATIVES FOR MANAGEMENT AND CONTROL OF SALINTIY

Three basic approaches, or a combination of these approaches might be used to achieve a solution to the salinity problem: do nothing, limit development or implement salinity controls. The first approach would achieve no management of salinity. Water resource development would be allowed to proceed with no constraints applied because of water quality degradation and with no implementation of salinity control works. This approach, in effect, ignores the problem and allows unrestrained economic development at the expense of an increased adverse economic impact resulting from rising salinity concentrations. The increases in future salinity levels and economic impact associated with this approach have been discussed in Chapter IV.

The second approach would limit economic or water resource development that is expected to produce an increase in salt loads or streamflow depletions. Such an approach would minimize future increases in the economic impact of salinity and possibly eliminate the need for salinity control facilities. However, it has the obvious disadvantage of possibly stagnating growth of the regional economy. Projections of future salinity levels and associated salinity detriments for this approach have been discussed in Chapter IV.

The third approach, calling for the construction of salinity control works, would allow water resource development to proceed. At least three possible management objectives could be considered: (1) salinity controls could be implemented to maintain specific salinity levels; (2) salinity could be maintained at a level which would minimize its total economic impact; and (3) salinity could be maintained at some low level for which the total economic impact of salinity would be equal to the impact that would be produced if no action were taken at all.

The following sections discuss an evaluation of the costs and benefits of various levels of salinity control and a comparison of the relative economics of the three basic salinity management approaches discussed above. This comparison forms the basis for the determination that the implementation of a basinwide salt load reduction program is the most feasible approach to achieving basinwide management of salinity.

POTENTIAL ALTERNATIVE BASINWIDE SALINITY CONTROL PROGRAMS

The potential measures for managing and controlling salinity concentrations presented in Chapter V were evaluated, and those which appeared most practical were selected for further investigation. Eight potential alternative salinity control programs incorporating a variety of control measures were formulated as a means of evaluating the magnitude, scope, and economic feasibility of a potential basinwide control program. These alternatives include three salt-load reduction programs, four flow augmentation programs, and one program to demineralize water supplies at the point of use.

The three salt load reduction programs utilized control measures such as desalination or impoundment and evaporation of mineral spring discharges, irrigation return flows and saline tributary flows, diversion of streams, and improvement of irrigation practices and facilities. These programs would acheive estimated salt load reductions of up to three million tons annually and would reduce average annual salinity concentrations at Hoover Dam by about 200 to 300 mg/l.

The four flow augmentation programs evaluated were based on three potential sources of water: increased precipitation through weather modification, interbasin transfer of water, and importation of demineralized sea water. The volume of flow augmentation provided by these programs would range from 1.7 to 5.9 million acre-feet annually. Resulting reductions in annual salinity concentrations at Hoover Dam would range from 100 to 300 mg/l.

The last alternative program evaluated would utilize desalination of the water supplies diverted to southern California as a means to minimize the adverse impact of salinity on the southern California water service area.

Average annual costs including amortized construction costs, operation costs, and maintenance costs, were estimated for each alternative program and ranged from $3 million to $177 million annually. The present worth of total program costs for each alternative from 1975 to 2010 would range from $30 million to $1,570 million. Estimated costs and resulting salinity concentrations are shown by program in Table 7. If no control or augmentation program were undertaken, comparable average salinity concentrations at Hoover Dam would be 876 mg/l and 990 mg/l in 1980 and 2010 respectively. Specific details used to compare and evaluate each alternative program are discussed in Appendix C, Chapter V.

The eight alternative programs evaluated were not directly comparable due to differences in the level of salinity control achieved, the multi-purpose aspects of some programs versus the singular salinity control natures of others, and the time required for implementation. Based on evaluation of a number of factors including total program costs, practicality, the implementation time period, salinity control benefits, and other benefits such as increased water supply, the phased implementation of a salt load reduction program

Table 7 Comparison of Alternative Salinity Control Programs

No.	Alternative Salinity Control Programs	Average Salinity Concentrations at Hoover Dam 1980 (mg/l)	Average Salinity Concentrations at Hoover Dam 2010 (mg/l)	Average Annual Program 1980 ($ Million/Yr)	Average Annual Program 2010 ($ Million/Yr)	Present Worth ($ Million)
1.	Salt Load Reduction (Full scale implementation)	620	720	47	47	510
2.	Salt Load Reduction (Phased Implementation)	700	700	23	52	350
3.	Flow Augmentation (Weather Modification) (1.7 MAF/Yr)	780	870	3	3	30
4.	Flow Augmentation (Interbasin Transfer) (2.5 MAF/Yr)	750	830	75	75	800
5.	Flow Augmentation (Interbasin Transfer) (3.9-5.9 MAF/Yr)	700	700	118	177	1,470
6.	Desalination (Source Control)	700	700	41	62	510
7.	Desalination (Supply Treatment)	--	--	140	160	1,570
8.	Desalination (Flow Augmentation) (2.0 MAF/Yr)	710	740	131	131	1,400

was selected as the least cost alternative for achieving basinwide management and control of salinity. Should the practicality of flow augmentation by weather modification be demonstrated by current pilot studies, however, the combination of such flow augmentation with a salt load reduction program would be a more optimal approach.

SALINITY MANAGEMENT COSTS

If salinity concentrations are reduced by the implementation of control measures, certain costs known as salinity management costs will be incurred. The form and magnitude of these costs depend upon a number of factors including the control measures utilized and the degree of salinity control achieved. Estimates of the probable costs and effects of the salt load reduction program, were utilized to evaluate the magnitude of salinity management costs for various levels of salinity control.

The major features of the salt load reduction program are presented in Table 8. This program was designed to reduce the salt load contributed by five large natural sources and twelve irrigated areas totaling 600,000 acres. Together, the five natural sources contribute about 14 percent of the Basin salt load. All of the irrigated areas selected exhibit high salt pick-up by return flows of about three to six tons per acre per year. Although this acreage comprises only about 20 percent of the Basin's irrigated load from irrigation sources above Hoover Dam. The specific control measures for the 17 component projects are listed in Table 8 along with project locations (also shown in Figure 5).

Average annual costs, including operation, maintenance, and amortized construction costs, were estimated for each of the 17 projects. For the five single-purpose salt load reduction projects, all costs were assigned to salinity control. The irrigation improvement projects would be multi-purpose. It is estimated they would produce various economic benefits of about the same magnitude as salinity control benefits and for this reason, only half of the costs of irrigation improvement were allocated to salinity control.

Estimates of the changes in streamflow depletions and salt load reductions were also prepared for each project. The five salt load reduction projects would remove an average of 172,000 acre-feet per year from the river system above Hoover Dam; of this amount, 140,000 acre-feet of demineralized water from the Blue Springs project would be available for use in central Arizona. The irrigation improvement projects would reduce non-beneficial consumptive water use by an estimated average of 299,000 acre-feet per year. The

Table 8. Salinity Management Data For Potential Projects

PROJECT DESCRIPTION			AVERAGE ANNUAL COSTS		EFFECTS AT HOOVER DAM				
No.	Location	Features	Total Proj. Cost ($1000)	Salinity Control Costs ($1000)	Flow Change (1000 AF/Yr)	Salt Load Reduction (1000 T/Yr)	TDS Reduction in mg/l		Cost Index ($/T)
							1980	2010	
1	Paradox Valley, Colorado	Stream Diversion	700	700	0	180	15	16	3.89
2	Grand Valley, Colorado	Irrigation Improvement	3,140	1,570	38	312	29	33	5.04
3	Lower Stem Gunnison River, Colorado	Irrigation Improvement	3,600	1,800	45	334	32	35	5.40
4	Price River, Utah	Irrigation Improvement	1,000	500	13	89	9	9	5.65
5	Las Vegas Wash, Nevada	Export & Evaporation	600	600	- 10	100	7	8	6.00
6	Uncompahgre River, Colo.	Irrigation Improvement	4,000	2,000	50	320	31	35	6.25
7	Big Sandy Creek, Wyoming	Irrigation Improvement	490	245	7	39	4	4	6.28
8	La Verkin Springs, Utah	Impoundment & Evap.	600	600	- 7	80	6	6	7.50
9	Roaring Fork River, Colo.	Irrigation Improvement	880	440	13	52	6	6	8.47
10	Upper Stem Colorado River, Colorado	Irrigation Improvement	1,420	710	20	80	9	9	8.88
11	Henry's Fork River, Utah	Irrigation Improvement	710	355	10	40	4	5	8.88
12	Dirty Devil River, Utah	Irrigation Improvement	710	355	10	40	4	5	8.88
13	Duchesne River, Utah	Irrigation Improvement	5,660	2,830	65	273	29	32	10.37
14	San Rafael River, Utah	Irrigation Improvement	1,360	680	18	65	7	8	10.48
15	Ashley Creek, Utah	Irrigation Improvement	830	415	10	36	4	4	11.55
16	Glenwood Springs, Colo.	Desalination	5,000	5,000	- 5	370	30	33	13.50
17	Blue Springs, Arizona	Export & Desalination	16,000	16,000	- 150	500	27	27	32.00
	Totals		46,700	34,800	127	2,910	253	275	--

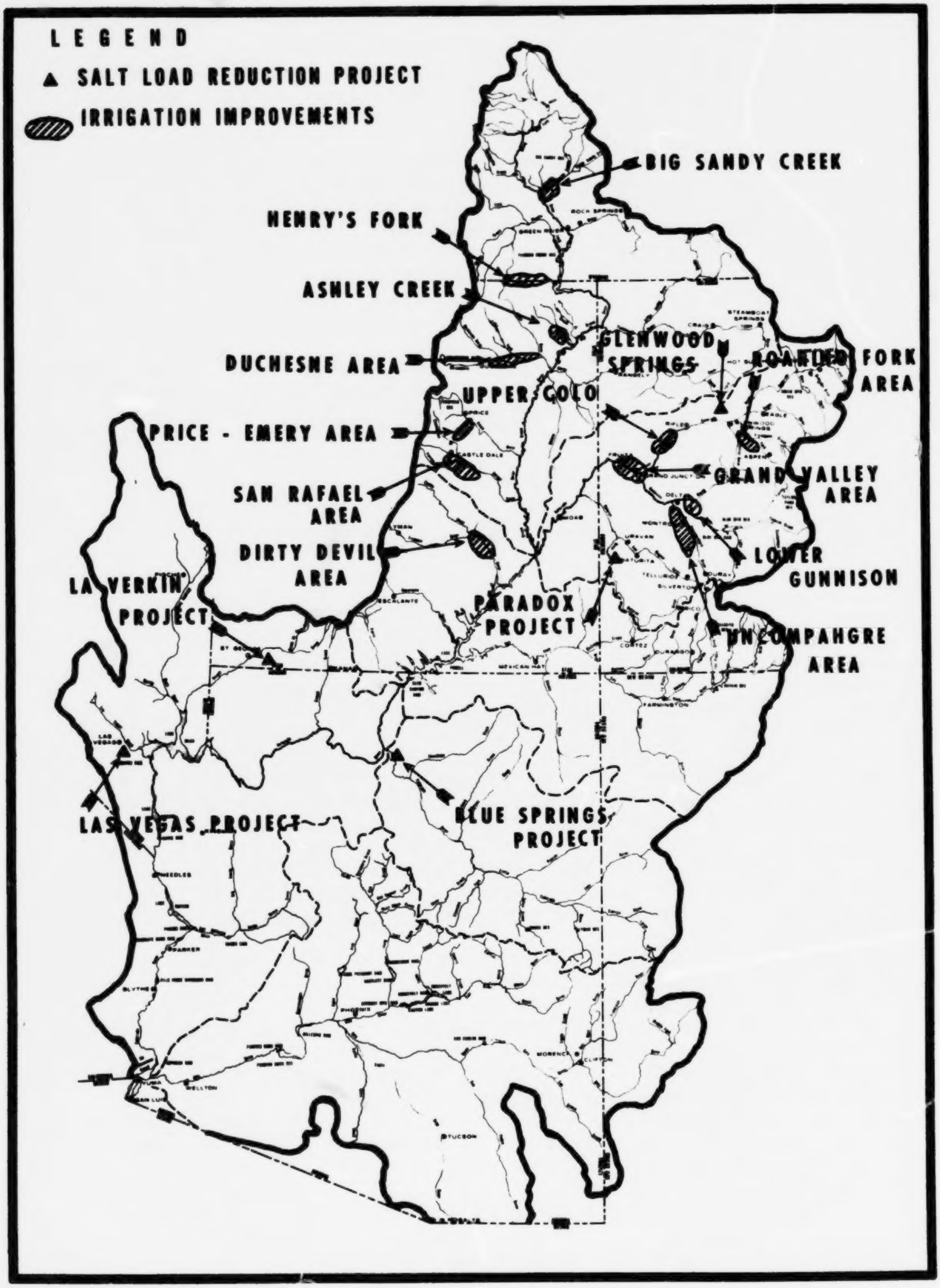
LEGEND
▲ SALT LOAD REDUCTION PROJECT
▨ IRRIGATION IMPROVEMENTS
BIG SANDY CREEK
HENRY'S FORK
ASHLEY CREEK
GLENWOOD SPRINGS
ROARING FORK AREA
DUCHESNE AREA
UPPER COLO
PRICE - EMERY AREA
SAN RAFAEL AREA
GRAND VALLEY AREA
DIRTY DEVIL AREA
LOWER GUNNISON
LA VERKIN PROJECT
PARADOX PROJECT
UNCOMPAHGRE AREA
LAS VEGAS PROJECT
BLUE SPRINGS PROJECT

Figure 5. Location of Potential Salt Load Reduction Projects

salinity control program would thus result in a net increase in available basin water supply of more than 250,000 acre-feet per year.

The incremental reductions in average salinity concentrations at Hoover Dam were estimated for each control project for the years 1980 and 2010 by utilizing predicted changes in flow and salt load. These incremental changes are shown in Table 8. Note that the salinity reduction for each project is greater in the year 2010 than in 1980. This factor results from decreases in average streamflow predicted to occur between 1980 and 2010.

A cost index utilizing estimated costs and salt load reductions was computed for each project. This index was then used to rank the projects in order of increasing unit cost of salt removal.

By utilizing the data in Table 8, salinity management cost functions relating cumulative salinity management costs to salinity reductions were prepared. These cost functions are also shown in Figure 6.

TOTAL SALINITY COSTS

For a given salinity level, there is an economic cost associated with water use (salinity detriments) and a second economic cost associated with maintaining salinity concentrations at that level (salinity management costs). The sum of these costs, defined as total salinity costs, can be determined for any time period and salinity level by the proper manipulation of three factors: the salinity detriment functions presented in Chapter IV, (Figure 4); the salinity management cost functions, (Figure 6); and the predicted future salinity concentrations with no control implemented, (Figure 2). Total salinity cost functions for various time periods are presented in Figure 7. The methodology utilized to develop these functions is discussed in Appendix C, Chapter V.

ECONOMIC AND WATER QUALITY EFFECTS

Salinity controls could be implemented to meet a variety of salinity management objectives which include both water quality and economic objectives. Since salinity levels and total salinity costs are interrelated, the selection of a water quality objective will result in the indirect selection of associated economic effects; conversely, the selection of an economic objective will result in the selection of associated salinity levels. A knowledge of the interrelationships between economic and water quality effects is thus

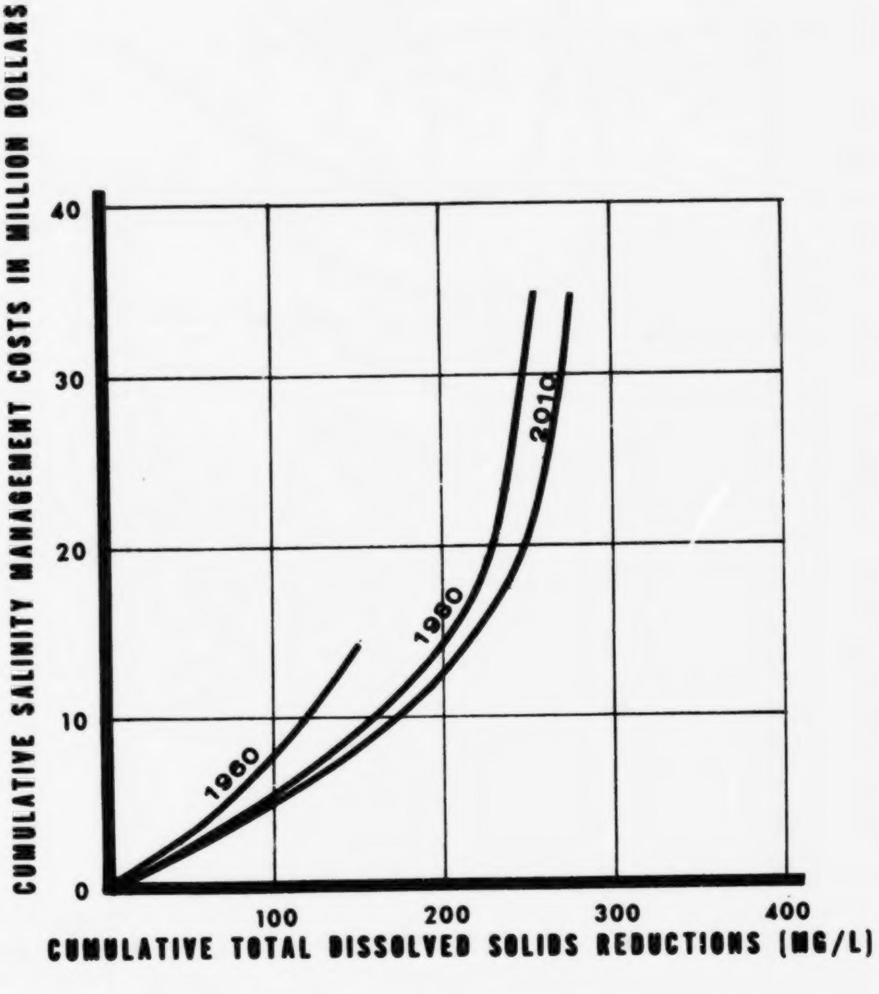

Figure 6. Salinity Management Costs

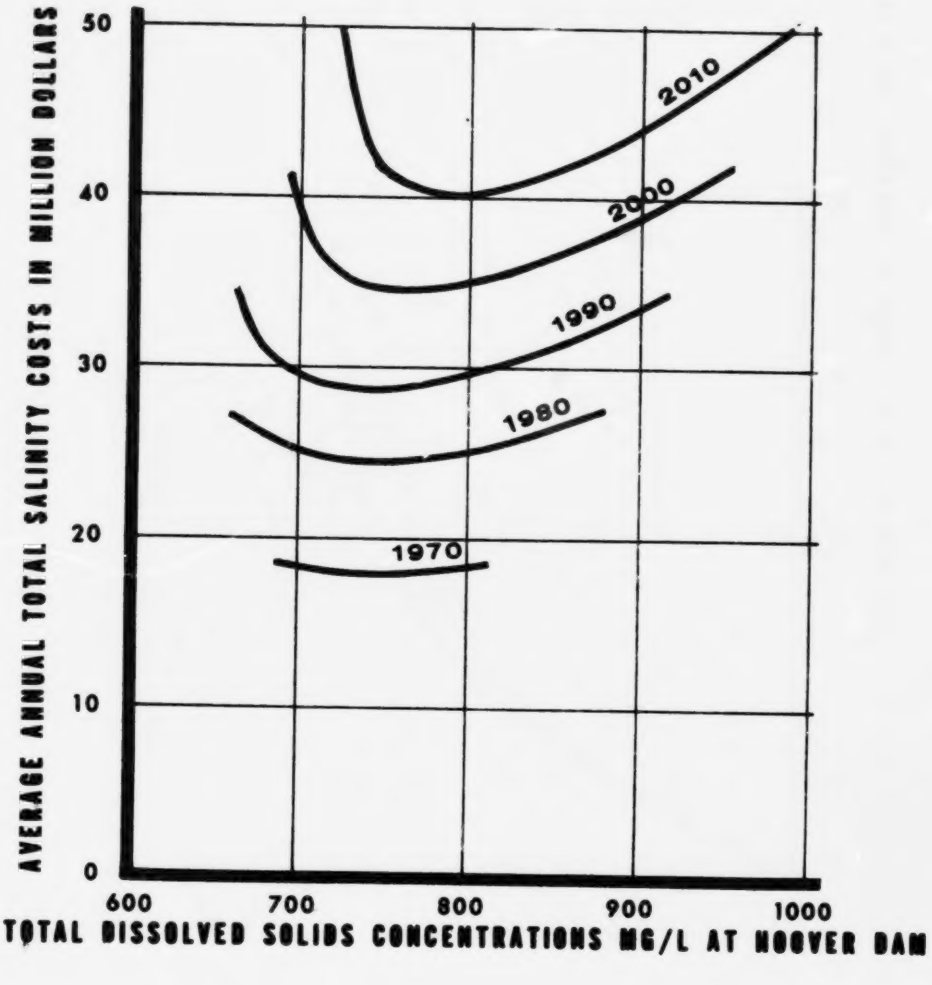

Figure 7. Total Salinity Costs

useful in the rational selection of salinity management objectives.

By utilizing the total cost functions shown in Figure 7, the economic and water quality effects associated with the three salinity management objectives were determined: (1) Maintain salinity at a level which would minimize its total economic impact and achieve economic efficiency (minimum cost objective); (2) Maintain salinity concentrations at some specified level (constant salinity objective); and (3) Maintain salinity at some low level for which the total economic impact would be equal to the economic impact that would be produced if no action were taken at all (equal cost objective). A comparison of the economic effects associated with these three objectives, in the form of variations in salinity costs with time, are shown in Figure 8. The economic effects associated with allowing unlimited water resource development in the absence of salinity control works (no control approach) and associated with the limited development approach are also shown in Figure 8.

Total salinity costs would be minimized by the limited development alternative. This approach might not be the most economical, however, when all effects on the regional economy are measured. Water resource developments are not constructed unless it has been demonstrated that such development will return economic benefits which exceed all costs of the development. A project which is economically feasible will thus produce a net improvement in the regional economy. If the project is not built, the net benefits of the project would be foregone representing an economic cost. A determination of the net economic benefits foregone if the limited development approach were utilized was beyond the scope of the Project's investigations. It is apparent from Figure 8, however, that if the annual benefits foregone exceed $3 million in 1980 and $11 million in 2010, the total economic impact of limited development would exceed the impact of the minimum cost alternative.

If unrestricted water resource development is permitted, implementing salinity controls to achieve the minimum cost objective would minimize total salinity costs. The no control and equal cost alternatives produce the identical highest average costs and most rapid increase with time of all the alternatives evaluated. Total costs associated with a constant salinity objective will fall somewhere between the extremes established by the other alternatives with the exact cost dependent upon the target salinity level. For a target level of 700 mg/l, total costs approximate minimum costs until 1990, then increase rapidly, eventually exceeding the no control costs. Beyond the year 2000, the rapidly increasing cost reduce the practicality of maintaining this salinity level. Selection of a higher target salinity concentration for the years 2000 and 2010 would reduce the total cost of this alternative.

One important observation can be made from Figure 8. Regardless of the alternative selected, the future economic impact of salinity will be great. Although implementing salinity controls will result in the availability of better quality water for various uses and some of the economic impact will be shifted from salinity detriments to salinity management costs, the total economic impact of salinity will not be substantially reduced. As a minimum, average annual total salinity costs will increase threefold between 1960 and 2010. Selection of the limited development alternative would reduce total annual costs by only about 40 percent below the no control alternative in the year 2010.

Variations with time of the predicted salinity levels associated with the five alternatives evaluated are shown in Figure 9. With no controls implemented, average annual salinity concentrations at Hoover Dam are predicted to increase between 1960 and 2010 by about 42 percent or 293 mg/l. Selection of any of the other alternatives evaluated would substantially reduce future salinity concentrations below the no control levels. Except for the limited development alternative, these reductions would result in the maintenance of average salinity concentrations at or below present (1970) levels for more than 25 years. Resulting water quality therefore would be consistent with non-degradation provisions of the water quality standards adopted by the seven Basin States. The limited development alternative would result in slight increases in average salinity concentrations.

COST DISTRIBUTIONS AND EQUITY CONSIDERATIONS

Although the total economic impact of salinity associated with each of the alternatives evaluated varies over a limited range, the distribution of salinity costs related to each alternative differs greatly. Distribution of costs may therefore be an important factor in the selection of alternatives. Associated with cost distribution are various equity considerations. These, too, influence the selection of alternatives. Salinity cost distributions for the five alternatives evaluated for both 1980 and 2010 conditions of water use are compared in Table 9. A further breakdown of salinity management costs, by individual projects, is shown in Table 8.

The no control and equal cost alternatives produced the extremes in the range of cost distributions evaluated. Total

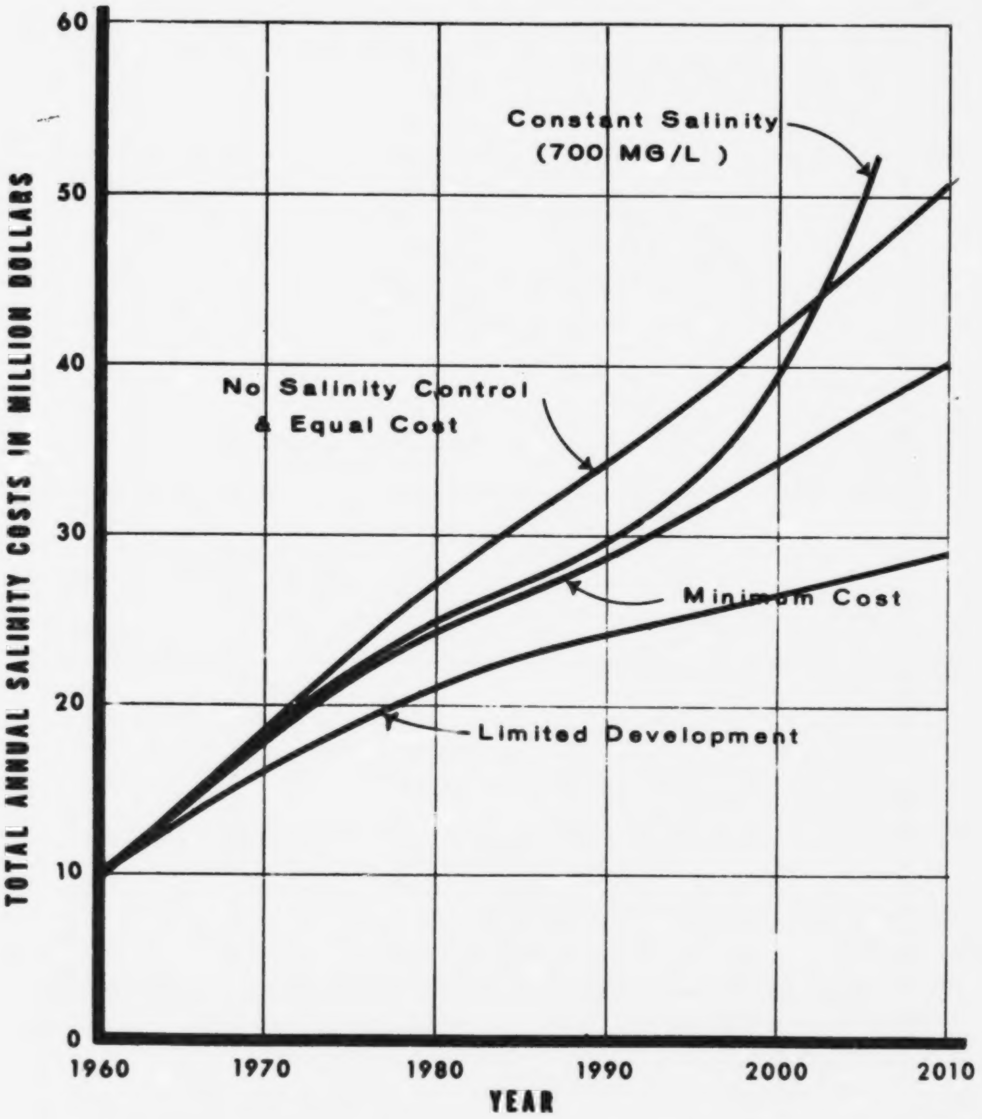

Figure 8. Salinity Costs vs Time

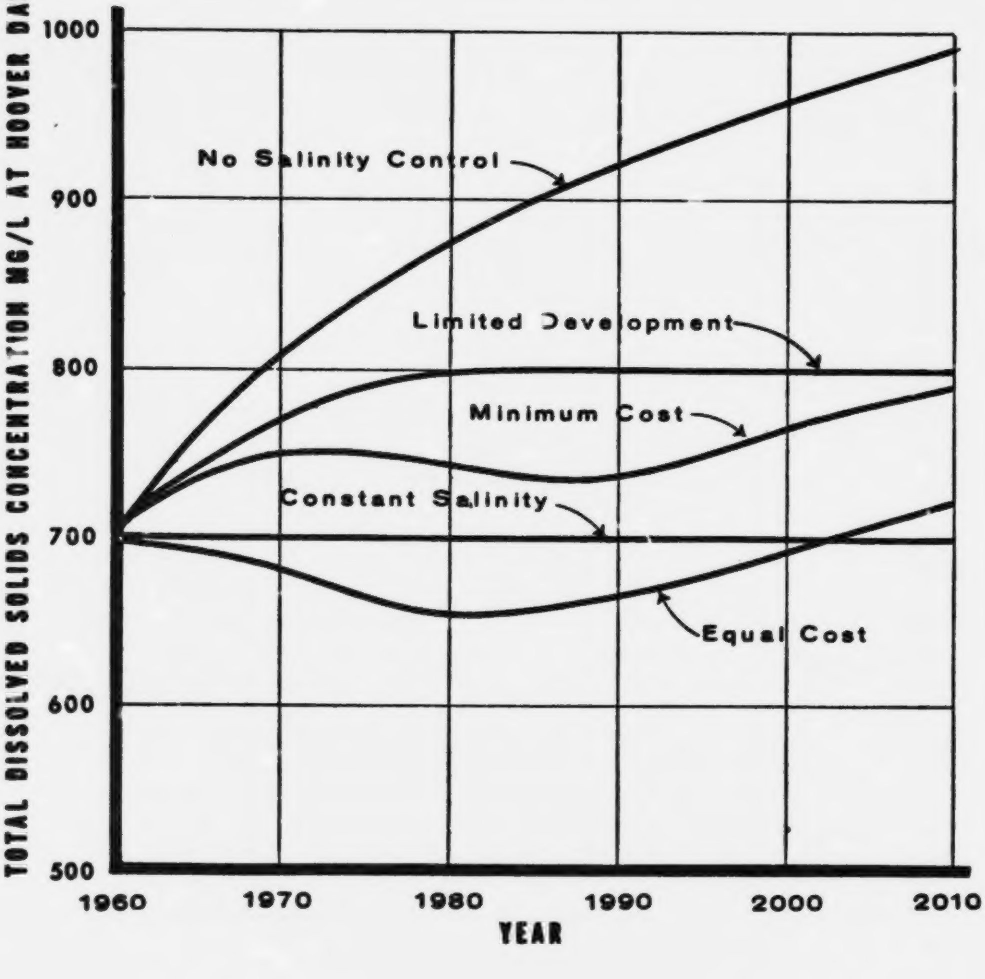

Figure 9. Salinity Concentration vs Time

costs for these two alternatives, by definition, are equal but the distributions of costs are vastly different. For the no control alternative, all costs are in the form of detriments. For the equal cost alternative, however, salinity detriments are reduced by an average of 60 percent. This cost reduction is offset by a corresponding increase in salinity management costs.

The extremes in the range of cost distribution point out the basis for equity considerations which may enter into the selection of management objectives. If the no control alternative is selected, all salinity costs would essentially be borne by water users and by the regional economy in the Lower Basin and southern California water service area. In contrast, selection of the equal cost alternative would redistribute a majority of the costs to investments in salinity control facilities in the drainage area upstream from Hoover Dam. Much of this investment would be for irrigation improvements in the Upper Basin, improvements that would produce substantial economic benefits in addition to salinity control benefits. The equity of these two extremes in cost distributions is vastly different.

Salinity detriments for the other three alternatives evaluated fall between the extremes extablished by the no control and equal cost alternatives. Salinity management costs are less than for the equal cost alternative. The equity of these cost distributions may also be an important factor in selection of the most desirable alternative. The cost distribution shown in Table 9 can be used to evaluate the relative costs and benefits of a given alternative. For example, a salinity control program designed to meet the minimum cost objective would have an estimated average annual cost of $7.2 million in 1980 and $12.7 million in 2010. The benefits associated with a given alternative would be the difference between salinity detriments expected if no controls are implemented and if the control program associated with that alternative is implemented. For the minimum cost alternative, average annual salinity control benefits would total $10.7 million in 1980 and $22.0 million in 2010.

LEGAL AND INSTITUTIONAL CONSTRAINTS

Implementation of a basinwide salinity control program based on salt load reduction projects would face a number of legal and institutional constraints. Perhaps one of the most formidable constraints would be imposed by existing State water laws and their requirements concerning water rights and beneficial use. These laws do not recognize utilization of water for quality control purposes as a beneficial use, yet several of the salt load reduction projects formulated would result in some minor depletion of water. Modification

Table 9 Comparison of Salinity Cost Distribution

Alternative Objective	Date	Salinity Detriments ($1,000/Yr)	Salinity Management Costs: Salt Load Reduction Projects ($1,000/Yr)	Salinity Management Costs: Salinity Control Costs ($1,000/Yr)	Salinity Management Costs: Total Salinity Management Costs ($1,000/Yr)	Total Salinity Costs ($1,000/Yr
No Control	1980	27,700	0	0	0	27,700
	2010	50,500	0	0	0	50,500
Limited Development	1980	21,000	0	0	0	21,000
	2010	29,000	0	0	0	29,000
Minimum Cost	1980	17,000	1,300	5,900	7,200	24,200
	2010	28,500	1,900	10,800	12,700	41,200
Constant Salinity (700 mg/1)	1980	13,500	1,900	10,000	11,900	25,300
	2010	19,000	25,000	13,500	38,500	57,500
Equal Cost	1980	9,200	6,900	11,600	18,500	27,700
	2010	21,000	17,600	11,900	29,500	50,500

of existing constraints would therefore be required to allow operation of these project facilities.

Improvement of irrigation efficiencies would reduce the amount of water required for diversion to a given farm or irrigation project. The effect of such a reduction in water use on perfected water rights is unclear and could cause legal problems. Such legal factors may affect the selection of control measures to be incorporated in a basinwide salinity management program.

The Water Quality Act of 1965 provided that the States establish water quality standards for all interstate streams. Subsequently, the seven Basin States developed water quality standards for the Colorado River. The standards established by the States did not include numerical salinity standards, primarily due to a lack of adequate salinity control information on which an implementation plan could be based. The Secretary of the Interior approved the water quality standards for the Colorado River, with the provision that numerical salinity standards would be established at such a future time when sufficient information had been developed to provide the basis for workable, equitable, and enforceable salinity standards. The states are thus still faced with the task of establishing suitable salinity standards in compliance with the Water Quality Act of 1965. The lack of numerical salinity standards may be a constraint to the rational planning of water resources development and implementation of salinity controls.

An important institutional factor for consideration is the lack of a single entity with basinwide jurisdiction to direct and implement a salinity control program. In addition, water quality and water quantity considerations are generally under the jurisdiction of different agencies at both the State and Federal level. This split jurisdiction poses coordination problems to all interests affected by a salinity control program.

Existing legal and institutional arrangements would also place constraints upon the means available to finance a salinity control program. In addition, a detailed analysis has not yet been made of the potential means for financing such a program. A cursory review of programs available for financing facilities similar to those contemplated indicated that existing financing schemes are not fully adequate to meet salinity control program needs. This is due either to an insufficient magnitude of available funds or a lack of legal authorization.

OTHER CONSIDERATIONS

The least cost alternative program, utilized as the basis for the evaluation of the economic feasibility of salinity control, was directed toward the objective of minimizing salinity concentrations on a basinwide basis. This objective was achieved by reducing the average salt load passing Hoover Dam, a control point for the quality of water delivered to most Lower Basin and all Southern California water users. It is important to note that salinity concentrations increase substantially between Hoover Dam and Imperial Dam due to water use in the Lower Basin and exports of water to the Metropolitan Water District of Southern California. Implementation of salinity control measures along the Lower Colorado River could offset or minimize these salinity increases. Such measures have a higher unit cost for salinity reductions at Imperial Dam than those measures selected for the least cost program and were omitted from consideration for this reason. Salinity control below Hoover Dam, however, is a possible, practical approach toward minimizing the economic impact of salinity and should receive further consideration in the formulation of a basinwide salinity control program.

Fluctuations in salinity concentrations resulting from factors such as seasonal changes in streamflow and water use occur throughout the Basin. Peak concentrations reached during such fluctuation may exert adverse effects on water use far exceeding the effects predicted on the basis of average salinity concentrations. By reducing average salinity concentrations, a salt load reduction program would provide a moderating effect on peak concentrations. The possible magnitude of such fluctuations and their adverse impact, however, would indicate the need for more positive means of minimizing peak concentrations. Possible control measures would include the manipulation of reservoir storage and releases, close control of water deliveries to minimize stream fluctuations, and seasonal storage of salts in irrigated areas. The water quality simulation model utilized to predict future salinity concentrations only determines long term average concentrations and does not have the capability to predict the magnitude of short term fluctuations. Water quality simulation capabilities therefore will need to be refined before the effectiveness of control measures can be evaluated.

CHAPTER VIII. ACTION PLAN FOR SALINITY CONTROL AND MANAGEMENT

The preceding chapters defined the present and expected future magnitude of the physical and economic impacts of salinity. Possible technical solutions to minimize these impacts including alternative approaches to management of salinity and associated water quality and economic effects were also discussed. The range of possible problem solutions point out the need for rational selection by the Basin states of objectives for future water quality and uses and the formulation of a basinwide salinity control plan to meet these objectives. This Chapter outlines a recommended plan of action to achieve an early solution to the salinity problem in the Colorado River Basin.

BASIC WATER QUALITY OBJECTIVE

In the past, the development of the Basin's water resources was primarily guided by two basic objectives: (1) full development of the water supply allocated to each State by applicable water laws and compacts, and (2) expansion of the regional economy. A number of legal, institutional and political factors have supported these basic objectives. The lack of consideration given to the water quality impact of such development has resulted in the creation of a serious water quality problem which has basinwide economic significance. There is thus the urgent need for a water quality objective to supplement these basic objectives and provide guidance in the optimal development of remaining water resources.

The Project's investigations have demonstrated that basinwide control and management of salinity is possible, practical and economically feasible. In addition, the feasibility of maintaining salinity concentrations at or below present levels in the Colorado River below Hoover Dam has been shown. The enhancement of water quality in the lower river would alleviate much of the future economic impact of salinity. Enhancement of the quality of the Nation's water resources has been declared a national policy. It is therefore recommended that a broad water quality objective be adopted by Basin interests which would require salinity concentrations to be maintained at or below present levels in the Lower Colorado River. This objective would become part of the basic policy guiding the comprehensive planning and development of the Basin's remaining water resources.

Salinity Standards

The present lack of numerical limits on salinity concentrations is a serious deficiency in the water quality standards established by the seven Basin States for the Colorado River and interstate tributaries. Salinity affects a number of water uses which are designated as uses to be protected by the standards. Suitable limits should be established to provide adequate protection for these designated uses.

In the initial process of establishing water quality standards pursuant to the Water Quality Act of 1965, salinity standards were not established, primarily due to a lack of information. Salinity levels which could be maintained by implementing controls were not known. More significantly, the economic effects of maintaining any given salinity level were also unknown. The Project's investigations have provided much of the needed information. Although additional effort will be required to establish detailed basinwide criteria which are equitable, workable and enforceable, present information is considered adequate to form the basis for the establishment of a salinity objective which will set an upper limit on salinity increases in the Lower Colorado River.

It is recommended that appropriate Colorado River Basin States take the steps necessary to establish a numerical objective for salinity concentration. Based on the factors discussed below, it is recommended that, as a minimum, this objective require the average concentrations of total dissolved solids for any given month to be maintained below 1000 mg/l at Imperial Dam. This would apply until such time as detailed basinwide criteria can be established as discussed in the following section.

Evaluation of the water quality effects of various salinity control alternatives has shown that by either implementing a basinwide salinity control program or limiting water resource development, future salinity levels at Hoover Dam could be maintained at or below an average annual concentration of 800 mg/l. A corresponding limit of 1000 mg/l at Imperial Dam could be achieved. A maximum limit based on average annual salinity concentrations would not provide water uses with adequate protection against potentially damaging short-term salinity fluctuations. A limit on average monthly concentrations is considered necessary to provide a more acceptable level of protection.

To achieve compliance with the basic policy objective to enhance water quality in the Lower Colorado River will require that detailed salinity criteria be established at a number of key locations throughout the Basin. These criteria will serve two purposes. By maintaining salinity levels at upstream locations below assigned limits, compliance with downstream criteria will be assured. Secondly, the criteria will provide a basis for optimal development of the water resources of a given tributary, sub-basin or State.

Complete Basinwide salinity criteria should be established after careful consideration by the Basin interests of such factors as existing salinity levels, proposed water resources development, the feasibility of salinity control, water quality requirements for water uses, and the economic impact of salinity. Such criteria should be consistent with the salinity policy and with the numerical objective outlined above, and should be adopted by January 1, 1973.

It is recommended that a State/Federal task group be established immediately to carry out the necessary activities to develop detailed salinity criteria for key control points in the Basin. Following completion of the Task Group's activities, the salinity criteria should be adopted by the appropriate Basin States in accordance with the Federal Water Pollution Control Act, as amended.

Task groups have been utilized in a similar manner in the Basin in the past. A task group was assembled to develop guidelines for establishing the initial water quality standards in the Basin. More recently, a task group was utilized to develop operating criteria for the large main-stem reservoirs.

To provide adequate consideration of all interests affected by salinity, the Task Group should include representation from Federal, State and local agencies. It would be desirable for state representation to include the State water pollution control agency and the State water resource agency. In view of Federal involvement in water resource development, water quality management, and the basinwide nature of the salinity problem Federal representation should include the Environmental Protection Agency, the Bureau of Reclamation, the Geological Survey, the Office of Saline Water, the Soil Conservation Service, the Agricultural Research Service and the International Boundary and Water Commission. Representation from other groups such as the Upper Colorado River Commission, Colorado River Commission of Nevada, Colorado River Board of California, and the Colorado River Water Users Association would be desirable.

SALINITY CONTROL AGENCY

One major constraint that must be overcome before basinwide management and control of salinity can be achieved is the lack of a single institutional entity with basinwide jurisdiction which could be responsible for planning and implementing a control program. There are various agencies with jurisdictions over parts or all of the Basin. In the case of the States, no suitable basinwide organizations exist. Several Federal agencies have basinwide responsibilities but no single agency has legislative authority to carry out all program elements. It would therefore appear necessary to create a new institution with the necessary authority to plan and implement a control program.

Three possible means of creating a salinity control agency are available. The Task Group assembled to formulate salinity criteria could continue to function and could be utilized to develop policy and plan a basinwide salinity control program. It would be heavily dependent upon member agencies to carry out the necessary program planning activities. A Task Group would be severly limited in its authority to require the States or Federal agencies to proceed with specific courses of action and would not have the necessary powers to fully implement a control program. No new legislative authority would be required to create this somewhat limited salinity control agency.

A second possible approach would be to extend the authority of an existing agency or commission to provide the necessary powers to carry out all the phases of a basinwide salinity control program. This approach would require changes in the authorizing legislation for the particular institutional entity selected for expansion of its functions.

Perhaps the most desirable approach would be to create a new permanent State/Federal agency or river basin commission with the authority to carry out all activities necessary to the basinwide management and control of salinity. Such an agency would have the advantages of concentrating all necessary powers in one agency and of being a single purpose institution with no conflict with other assigned functions. New legislation would be required to create the agency.

In view of the magnitude and scope of the salinity problem and possible solutions, it is recommended that the third approach be taken and that legislation be sought to establish a permanent State/Federal agency or river basin commission with the authority to plan, formulate policy, direct, and implement a basinwide salinity control program. Consideration should also be given to the possibility of extending the authority of existing agencies or commissions to assume this responsibility.

BASINWIDE SALINITY CONTROL PROGRAM

A large-scale salt load reduction program was identified in

Chapter VII as the least cost alternative means of achieving basinwide control of salinity. The steps which must be taken to authorize, fund, plan and implement such a program are outlined in the following paragraphs.

Legislative Authorization

Existing legal and institutional arrangements are not adequate to provide the basis for implementing a large-scale salinity control program. It is therefore recommended that the necessary congressional authorization and funding be sought at an early date so that the implementation of the salinity control program can proceed.

Due to the scale and types of control projects included in the salt load reduction program an approach similar to that utilized for the authorization and funding of water resources developments is recommended. Water resource projects normally move through three basic steps before they are placed in operation. A project is first authorized by Congress on the basis of preliminary plans developed by limited studies known as reconnaissance studies. Following authorization, funds may be appropriated for more detailed planning investigations known as feasibility studies, a feasibility report is submitted to Congress, and construction funds are requested. The third step begins when funds are appropriated for construction. Completion of construction then places the project in operation.

Frequently, a number of related projects are authorized by a single legislative act. This was the case for the Colorado River Storage Project Act which authorized several large reservoir projects at one time. It is recommended that legislation be introduced in the near future to authorize the entire basinwide salt load reduction program and to appropriate funds for the necessary planning studies.

Planning Phase

In line with the three steps outlined above for authorizing and funding a water resource project, once authorized, the basinwide salinity control program should be conducted in two phases, a planning phase and an implementation phase. This section outlines the activities which make up the planning phase.

The planning phase of the basinwide program should be directed toward the objectives of providing sufficient information for developing an implementation plan, and of providing the feasibility reports on which requests for construction funds for necessary control works can be based, and of identifying construction, operation and related costs which should be properly assigned to the Basin States and other beneficiaries. To achieve these objectives will require substantial efforts to be expended in five types of activity: systems analyses, research and demonstration activities, reconnaissance investigations, feasibility studies and legal, institutional and financial evaluations.

System Analyses. A systematic evaluation of the quality and economic aspects of the salinity problem provided a key element in the Project's determination of the potential feasibility and practicality of a basinwide salinity control program. Systems analysis capability similar to the methodology developed for this evaluation will be required for the planning phase. Refinement and updating of the analytical tools will be required, however, to provide adequate capability for the improved information developed by other planning activities. Specifically, a refined water quality simulation model and updated economic evaluation models will be required.

The Project's water quality simulation model is basically a water and salt budget model with the capability to predict long term averages for streamflow, salt loads and salinity concentrations at various points in the basin and to evaluate the long term effects of modifications in water use and salt loading at any point in the river system. This model is not capable of predicting fluctuations in salinity concentrations or of evaluating the short term effects of various control measures. The model should be refined to provide for simulation of water quality on a monthly basis including the routing of salt loads through irrigated areas and large reservoirs. This improved model would have the capability to evaluate the water quality effects of proposed annual operating plans for the major reservoirs of the basin, to optimize reservoir operations to minimize salinity fluctuations, to provide an improved degres of evaluation of the salinity impacts of proposed water resource development projects and to assist in the formulation of suitable numerical salinity standards in addition to its utilization for evaluation of alternative salinity control measures and facilities.

The Project's economic evaluations and models were largely based on 1960 economic data. The economic impact of salinity increases in specific areas in the Upper Basin and Mexican water users was not evaluated. The effects of rising salinity levels in the Colorado River supply on the feasibility of controlling the salinity of the Salton Sea was not considered. Economic effects were based on average salinity concentrations and fluctuations in concentrations were not evaluated.

Updating the economic models on the basis of 1970 economic data which should be available by 1972 would provide a better estimate of the current detrimental effects of salinity and would improve predictions of future effects since historical trends from 1960 to 1970 would be available. In view of the probable economic impact of salinity on Mexican water users, on water use in certain areas of the Upper Basin and on control of salinity in the Salton Sea, the economic models should have the capability for handling such areas. In addition, the capability to evaluate the economic impact of salinity fluctuations should be developed.

Research and Demonstration Activities. A number of research and demonstration activities discussed in Chapter V are currently directed toward improvement of salinity control technology. Completion of these activities will not provide the technology needed for control of all types of salinity sources. Additional research will be required if certain types of salinity sources are to be controlled.

The greatest lack of available technology is in the area of natural diffuse sources. Control of salt contributed by surface runoff and diffuse groundwater sources, although the major sources of salt-loading in the Basin, is presently not technically feasible. The Soil Conservation Service, the Bureau of Reclamation, the Geological Survey, the Bureau of Land Management and various State agencies are all concerned with various aspects of water and land utilization which may have an impact on diffuse salt contributions. It may be possible to conduct research or demonstration efforts through these agencies programs to develop means of minimizing diffuse salt contributions.

Control measures applicable to natural point sources are limited, especially in areas with low evaporation rates. The Geological Survey has an extensive reserach program in the field of groundwater quality and movement. Directing some of this research effort toward mineral springs could result in the development of additional control measures.

Another area for which present control technology is limited is irrigated agriculture. Research concerning various irrigation practices and facilities, crop yields, and land characteristics being carried out by various State institutions, the Bureau of Reclamation, the Soil Conservation Service and the Agricultural Research Service may be expanded to include salinity control aspects.

Reduction of salt loads from irrigated agriculture utilizing present technology as contemplated for the salt load reduction program previously discussed will require the education of irrigators with regard to improved practices and will require a substantial investment by irrigators for improved facilities. Demonstrations of the economic benefits associated with proposed improvements will be required to provide the incentive for irrigators to make the necessary changes. Such demonstrations would also show the technical feasibility of such control measures with regard to water quality improvements. The Bureau of Reclamation, the Soil Conservation Service, the Agricultural Stabilization and Conservation Service, the Extension Service, various water user's associations and other state agencies conduct programs which could assist in such education and demonstration efforts.

Completion of reconnaissance and feasibility studies discussed in the following sections will be dependent upon completion of research and demonstration activities in some cases. This fact coupled with the time span required for completion of most research efforts would indicate the need for early initiation of desired additional research and demonstration efforts.

Reconnaissance Investigations. Preliminary, limited scope investigations known as reconnaissance investigations were completed in sufficient detail to provide the basis for seeking appropriations of funds for feasibility studies for only two of the seventeen projects included in the salt load reduction program. Reconnaissance investigations would thus be required for the other 15 projects. In addition, similar investigations should be made of control measures along the Lower Colorado River below Hoover Dam, in the Yuma Valley area with respect to the salinity of Mexican water deliveries and in the Salton Sea area where such controls might alleviate rising salinity levels in the Sea. Such investigations could best be performed by the water resource development agencies at both the State and Federal level. The Bureau of Reclamation is currently conducting a planning study for rehabilitation of irrigation facilities for the Uncompahgre Project, Colorado, which could be expanded to include the desired salinity control reconnaissance investigation.

An evaluation of the results of the reconnaissance investigations would provide the basis for initiation of feasibility studies for those control projects showning economic feasibility at the reconnaissance level.

Feasibility Studies

Feasibility studies are planning studies which go into much greater detail than reconnaissance investigations and frequently require extensive and costly field investigations. For this reason, such studies should be conducted for only those control projects which could reasonably be constructed to meet salinity management objectives. Such studies would provide the basis for seeking appropriations for actual project construction.

Legal and Institutional Evaluation

Constraints imposed by legal and institutional factors may significantly alter the range of available salinity control measures. Detailed evaluations of existing legal and institutional constraints which may affect the basinwide salinity control program should be conducted. Where modifications of existing legislation or institutional arrangements are needed to allow a rational approach to management of salinity, such modifications should be identified. Emphasis should be placed on evaluations of the various water laws controlling use and distribution of Colorado River water.

Implementation Phase

The final or implementation phase of the basinwide control program would include the appropriation of construction funds, the actual construction of projects, and the actual management of salinity through operation of control works.

As feasibility studies are completed, a final implementation plan should be developed which would be directed toward meeting the established numerical salinity standards. Feasibility reports for the control projects included in the final plan should then be submitted to Congress and construction funds requested. Funds should be made available according to the construction schedule established by the implementation plan. Since the implementation of control works will be dependent to some extent upon the rate at which water resources development proceeds, the actual construction of control projects could extend over a lengthy period.

Once control measures are implemented, provision will need to be made for funding for continued operation and maintenance as most facilities will be need continuously for the foreseeable future.

THE MINERAL QUALITY PROBLEM IN THE COLORADO RIVER BASIN

APPENDIX A

NATURAL AND MAN-MADE CONDITIONS AFFECTING MINERAL QUALITY

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGIONS VIII AND IX

1971

THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency was established by Reorganization Plan No. 3 of 1970 and became operative on December 2, 1970. The EPA consolidates in one agency Federal control programs involving air and water pollution, solid waste management, pesticides, radiation and noise. This report was prepared over a period of eight years by water program components of EPA and their predecessor agencies--the Federal Water Quality Administration, U.S. Department of Interior, April 1970 to December 1970; the Federal Water Pollution Control Administration, U.S. Department of Interior, October 1965 to April 1970; the Division of Water Supply and Pollution Control, U.S. Public Health Service, prior to October 1965. Throughout the report one or more of these agencies will be mentioned and should be considered as part of a single agency--in evolution.

PREFACE

The Colorado River Basin Water Quality Control Project was established as a result of recommendations made at the first session of a joint Federal-State "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries," held in January of 1960 under the authority of Section 8 of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.). This conference was called at the request of the States of Arizona, California, Colorado, Nevada, New Mexico, and Utah to consider all types of water pollution in the Colorado River Basin. The Project serves as the technical arm of the conference and provides the conferees with detailed information on water uses, the nature and extent of pollution problems and their effects on water users, and recommended measures for control of pollution in the Colorado River Basin.

The Project has carried out extensive field investigations along with detailed engineering and economic studies to accomplish the following objectives:

(1) Determine the location, magnitude, and causes of interstate pollution of the Colorado River and its tributaries.

(2) Determine and evaluate the nature and magnitude of the damages to water users caused by various types of pollution.

(3) Develop, evaluate, and recommend measures and programs for controlling or minimizing interstate water pollution problems.

In 1963, based upon recommendations of the conferees, the Project began detailed studies of the mineral quality problem in the Colorado River Basin. Mineral quality, commonly known as salinity, is a complex Basin-wide problem that is becoming increasingly important to users of Colorado River water. Due to the nature, extent, and impact of the salinity problem, the Project extended certain of its activities over the entire Colorado River Basin and the Southern California water service area.

The more significant findings and data from the Project's salinity studies and related pertinent information are summarized in the report entitled, "The Mineral Quality Problem in the Colorado River Basin." Detailed information pertaining to the methodology and findings of the Project's salinity studies are presented in three appendices to that report - Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality," Appendix B, "Physical and Economic Impacts," and Appendix C, "Salinity Control and Management Aspects."

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CHAPTER I. INTRODUCTION

As a part of its overall study of the mineral quality problem, the Colorado River Basin Water Quality Control Project (Project) carried out a thorough review and analysis of past water quality data, and made detailed field investigations of present conditions. These studies included a thorough review of factors which affect mineral quality of streams, review of previous investigations of the mineral quality problem in the Colorado River Basin and other similar basins, a rigorous statistical analysis of existing mineral quality data, and extensive field studies to determine the location and magnitude of salinity sources throughout the Colorado River Basin.

This Appendix includes a discussion of the factors which affect mineral quality in streams, a description of the statistical methods utilized in the analysis of existing water quality data and a summary of the findings, a description of the methods employed in the field studies, and a summary of the findings regarding sources of mineral salts within the Colorado River Basin.

Detailed compilations, discussions, and interpretations of data obtained in the field studies are available in open file reports at the Project Office at the Federal Center, Denver, Colorado. Printouts of analytical results and field measurements have been furnished to the Conferees and are available for review at the Project Office.

CHAPTER II. FACTORS WHICH AFFECT MINERAL QUALITY OF STREAMS

A clear distinction exists between the two basic causes of salinity increases in streams. These may be referred to as the salt loading and salt concentrating effects. The former is associated with the discharge of additional mineral salts into the stream system in municipal and industrial wastes, in irrigation return flows, and in water from natural sources. In other words, the salt load returned to the stream is greater than that diverted thereby increasing the salt burden in the stream. In contrast, the salt concentrating effect occurs as a result of consumptive use of water. No mineral salts are added, but the salt concentration increases as a result of water lost from the stream system. Some of the salt loading and salt concentrating factors that influence water quality are discussed in the following section.

SALT LOADING EFFECTS

Municipal and Industrial

The use of water for domestic purposes increases the mineral content of water in several ways. Washing, bathing, and laundering, of beings and things, make use of the principle of solution and disposal of mineral matter. The human body concentrates the mineral constituents in the food and water which passes through the digestive system. Water is forced to live up to its reputation as the "universal solvent" in an endless variety of ways in domestic use.

Municipalities having surface supplies of domestic water may add to or subtract from the total salt burden carried by the affected stream, but the waste water returned to the stream always has a higher mineral concentration than that of the diverted water. Municipalities which have ground water supplies and discharge waste water to surface streams always add salt loads to the receiving streams.

Industrial use of water affects mineral quality of streams much the same way as municipal uses. Water is used in many processes which employ its solvent properties, and in others, such as floatation, where solution of mineral matter is a side effect. Many industries utilize ground-water supplies; and discharge waste water to surface streams thereby adding to their salt load.

Mining and milling industries may contribute salts through seepage from waste holding ponds, tailings piles, and direct discharge of process wastes. Many mines intersect fissures and pervious formations containing highly mineralized water which may discharge to surface streams.

Brines and brackish waters are often brought to the surface by oil and gas drilling operations and by producing wells. Existing regulations are inadequate from the standpoint of limiting the quality of water discharged to surface streams. Discharge of brackish oil field water to streams can contribute substantial salt burdens.

Mineral exploitation, such as oil shale processing and subsurface nuclear explosions, may contribute mineral salts to surface streams unless such activities are properly monitored and regulated.

Irrigation

Irrigation contributes salt loads to streams through return flows. Water is diverted from streams and applied to the land in varying amounts depending upon the type of crops being grown. Some of the diverted water is consumed by evaporation and transpiration and some is returned to the stream system by way of canal wasteways and surface drains. Some of the water seeps into the soil and may or may not find its way back to the stream from which it was diverted.

Sources of water entering the soil profile include seepage from conveyance systems, deep percolation from irrigated lands, and seepage from tail water and other wastes. Wherever this water is in prolonged contact with the soil, it tends to reach a chemical equilibrium with the soil. The result may be either the dissolution of salts from the soil profile or precipitation of salt in the soil profile. In the Colorado River Basin, evidence indicates that salts are generally dissolved from the soils. However, authorities differ in their estimates(1,2,3) of the amount of salts that will be dissolved and on the length of time solution will persist following the initiation of irrigation. Some believe that with proper irrigation practices, solution of salts will be inconsequential after a brief "initial leaching." On the other hand, it seems apparent that solution of salts will persist in some cases. Water may travel a considerable distance in its underground route back to the stream system. Thus, there is ample time for the water to approach a state of chemical equilibrium with the soil formation. Soils yield soluble minerals through the process of weathering and decomposition. The solution process will proceed as long as the water in contact with the soil has not attained chemical equilibrium with the soil mass.

The amount of soil material dissolved depends upon a number of factors, including the type of soil, the quality of applied water, the length of the flow path, and the partial pressure of carbon dioxide.

Out-of-Basin Diversions

Much of the service area for Colorado River water lies outside the confines of the Basin. The amount of water diverted from the Colorado River into adjoining basins is shown in the following tabulation.

Diverted To	Amount (Acre-feet/year)
Platte River Basin[1/]	388,000
Arkansas River Basin[1/]	71,000
Rio Grande River Basin[1/]	2,000
Bonneville Basin[2/]	103,000
Southern California[3/]	4,425,000
Mexico[4/]	1,580,000
Total	6,569,000

Diversions from the Upper Basin are generally made near the high mountains which serve as the source of the river's water supply. Water from these mountainous areas is generally of excellent quality (below 100 mg/l TDS). Thus, these diversions do not effectively reduce the salt load of the Colorado River system. On the other hand, Lower Basin waters are of relatively poor quality so that a substantial salt load is removed when water is diverted from the stream system. Where the diverted water is exported out of the Basin, as in the case of diversions to Los Angeles and to the Imperial and Coachella Valleys, the salt load is removed from the Colorado River Basin system. In these cases, a portion of the diverted supply must

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[1/] Water Resources Data for Colorado, U. S. Geological Survey, 1967.
[2/] Iorns, et al, U. S. Geological Survey Professional Paper 441.
[3/] California Water Bulletin for 1966.
[4/] International Boundary Water Commission Water Bulletin, 1963.

leave the receiving area in order to purge imported salts from the systems served. Future diversions to the Gila River Basin by way of the Central Arizona Project will remove salts from the surface stream system since there will be no return of water from this project to the Colorado River. Present and future diversions are discussed more fully in Appendix B of this report.

Natural Sources

The natural sources of salt may be classified as discrete or diffuse. Discrete, or point sources include springs, or seeps, which issue as a single flowing stream, or as a series of such streams within a relatively small area. In contrast, diffuse natural sources are characterized by salt accretions from large drainage areas. In the Colorado River Basin, diffuse sources are generally of much greater magnitude than point sources.

Point Sources

A significant portion of the salt load in the Colorado River Basin issues from saline mineral springs which occur throughout the Basin. In this report, flowing wells are treated as discrete sources of salinity.

Diffuse Sources

In the Colorado River Basin, virtually all the stream flow and much of the salt load arise in the form of spring runoff. Much more moisture falls on the uplands and high mountains than in the lowlands and valleys. Because of both an increase in precipitation and a decrease in evaporation with increasing elevation, the upland areas yield most of the runoff while the lowland areas yield almost no surface flow except during and immediately following storms.

A portion of the precipitation which falls on the land surface is evaporated, while some flows overland to enter nearby streams. Some of the water which percolates into the soil may subsequently rise by capillary action and evaporate. Soil moisture may likewise be transpired by plants, move to nearby streams, or enter the ground-water reservoir. In each case, except for direct evaporation, there is a potential mechanism for solution of salts from the soil. Overland flow may pick up soluble salts stranded at the soil surface by evaporation of the capillary water. Streamflow enters bank storage in times of high stream stage and while in bank storage, the water dissolves minerals from the alluvial soils. Salts dissolved may be concentrated by the removal of water through phreatic evaporation. During periods of low streamflow, water emerging from bank storage will contain the salts leached from the alluvial formations. Precipitation entering the soil may emerge far downstream as the mineralized flow of springs or wells, or it may emerge in nearby streams as upwelling ground-water. Salts contained in these flows have been leached from the soils and rocks enroute to the streams.

As a result of the interaction between soil and water, the mineral quality of a stream is closely related to the geology and soils of its drainage area. The upland areas of the Colorado River Basin are, for the most part, composed of crystalline rocks which are resistant to weathering and contain few soluble minerals. These factors coupled with the relatively large amount of precipitation and restricted leaching opportunity result in runoff with low concentrations of dissolved solids, although the total salt load per unit of contributing land area is relatively large. The lowland valleys were created by erosion and deposition of mineral solids.

Thus, water which comes in contact with valley soils dissolves deposited mineral salts and transports them to nearby streams. Formations in some of these areas yield relatively high concentrations of mineral salts. Examples of such formations include: the Paradox formation which is composed of halite, gypsum, and anhydrite; Mancos shale which contains abundant amounts of gypsum; and the saline facies of Tertiary lake beds. In the Upper Colorado River Basin, Iorns(4) has more extensively documented this relationship between the geology of various areas and mineral quality of streams in those areas.

SALT CONCENTRATING EFFECTS

The consumptive loss of water from the stream system reduces the amount of water available to transport incoming salt loads. As a result, water consumption increases the downstream concentration of salts. Ways in which salinity concentration may be increased by removal of water from the stream system are discussed briefly in the following sections.

Municipal and Industrial

A number of municipal and industrial uses cause salt concentrating effects. Thermal electric power plants are a good example of this form of mineral quality degradation. Such plants normally add very little salt to a stream. However, they deplete the supply of water by evaporation, thus concentrating mineral salts into an ever-decreasing volume of water. The residual salts are removed from the power plant by "blowdown" water from the system. If the "blowdown" is returned to the stream system, it will return a quantity of salt approximately equivalent to the amount withdrawn. Thus, the net effect of the power plant is to consume water without affecting the salt burden of the river. The result is an increase in mineral quality in the stream. However, even if the "blowdown" were excluded from the stream system, the power plant would also affect mineral quality. The nature of this effect is discussed in considerable detail in the following section.

Irrigation

Irrigation entails consumptive use of water through evaporation, transpiration, and through seepage losses, where these losses do not return to the stream system. Wherever such water losses occur upstream from significant salinity sources, they may be expected to cause mineral quality deterioration. Removal of water from the stream above a salinity source diminishes the amount of water available for dilution of salts from that source. The impact of that salinity source on stream quality will therefore be increased by the consumptive loss of water. Thus, any removal of flow from a stream, for any purpose will adversely effect downstream water quality. This relationship is frequently overlooked since there may be no effect in the immediate vicinity of the water-using activity. Since irrigation depletes a significant quantity of flow from the Colorado River system, the salt concentrating effect of irrigation is especially important. Records indicate that an excessive amount of water is applied to irrigated lands in some areas of the Colorado River Basin. One reason is that irrigators feel compelled to use all the water historically diverted in order to maintain their water rights. Another reason is the lack of widespread understanding of the amount of irrigation water required to meet evapotranspiration and salt balance requirements. A third factor is the inadequacy of most irrigation systems to operate in accordance with irrigation demands. These systems generally serve water on a "rotation" basis so that the irrigator must use water when it is available to him, rather than when his crops need it. Whatever the justification, excessive consumptive use of irrigation water causes a detrimental increase in the concentration of mineral salts in the Colorado River Basin.

Out-of-Basin Diversions

Exportation of water from the Colorado River Basin increases salt concentrations below the points of diversion in the same way as other stream depletions. This concentrating effect is partially offset by the removal of salt from the Basin, as explained previously. However, in the Upper Colorado River Basin, diversions generally occur in the headwaters areas where salt concentrations are relatively low. For this reason, the net effect of these exports is to increase downstream salinity levels through reduction in available dilution water.

In the Lower Colorado River Basin, the major out-of-Basin diversions are at Parker Dam where nearly a million acre-feet of water is diverted for distribution by the Metropolitan Water District of Southern California and at Imperial Dam where water is diverted to the Gila Gravity Canal and the All-American Canal for irrigation and domestic uses in southwestern Arizona and southern California. These diversions remove water which would otherwise be available for dilution of downstream salt loads; however, the detrimental effect is partly mitigated since they also remove large quantities of salt.

Most of the seven Basin States have elected to utilize a portion of their allocated share of Colorado River water outside the confines of the Basin's drainage area. Thus, excluding Mexico, some five million acre-feet of water are currently exported from the Basin. The major exports are in California and Colorado; however, other Basin States are actively developing means for exportation of a part of their allocated share of the Basin's water supply. These planned out-of-Basin diversions will serve water to regions in the vicinity of Cheyenne, Albuquerque, Salt Lake City, and the Phoenix-Tucson area. Planned increases in the amount of exportation are as follows: Colorado, 432,000 acre-feet; New Mexico, 110,000 acre-feet; Utah, 144,000 acre-feet; Wyoming, 22,000 acre-feet; Arizona, between 676,000 and 1,321,000 acre-feet. Thus, future out-of-Basin exports will account for about half of the water supply of the Colorado River Basin.

The increase in out-of-Basin diversions, particularly those in the Upper Basin, will result in further degradation of mineral quality in the Colorado River system unless some means are found for augmenting the Basin's water supply with good quality waters.

CHAPTER III. HISTORIC CHANGES IN WATER QUALITY

INTRODUCTION

Those concerned with water resources of the Colorado River Basin generally recognize that changes have occurred in the mineral quality of surface waters of the Basin. This belief stems from the knowledge that development of the water resource projects and consumptive use of the water result in degradation of water quality. Although other studies of mineral quality of Basin streams have alluded to such changes, there has been no clear delineation of those changes which are associated with normal fluctuations in hydrologic patterns and those changes which can be attributed to man's activities.(4,5) The Project attempted to fulfill this need by rigorous application of standard statistical tests to the mass of historical data that has been compiled.

The Project's statistical analysis of existing mineral quality data was designed to:

(1) Identify the statistically significant changes in mineral quality with respect to time and distance.

(2) Provide a basis for development of sound conclusions regarding relationships to natural and man-made hydrogeological factors.

(3) Assist in the selection of points and/or stream reaches where additional sampling was needed.

CHANGES IN WATER QUALITY WITH RESPECT TO TIME

Statistical Methods Employed

Long-term mineral quality data developed by the U. S. Geological Survey, the Metropolitan Water District of Southern California, and the

Agricultural Research Service were utilized in the study. Quality and streamflow data from twenty-seven stations representing 353 station-years were analyzed. Many of the records dated from the early 1940's and a few began in the late 1920's. In all cases, the most recent data utilized was for water year 1963.

Preparation of Input Data. Total dissolved solids (TDS) or total filterable residue was chosen as the parameter of interest. The total dissolved solids determination is a broad analytical procedure encompassing all of the constituents involved in salinity concentrations in a stream. Moreover, TDS was the only parameter, other than pH or specific conductance, which was reported continuously throughout the periods of record for each sampling location.

Since the analytical results reported for any individual sample may have represented a variable time period based upon the collecting agency's procedures at the time of collection, it became necessary to develop a common time base for total dissolved solids concentration at all stations. The most logical time base appeared to be the 30-day month, since very few samples were composited for longer periods and the use of monthly values still permitted input of sufficiently large numbers of values for the statistical analysis.

Two methods of deriving a representative TDS value for each 30-day month were considered. The flow-weighted mean concentration may be thought of as representing the composition of all the water that passed the sampling point during the period of interest and it is approximately the result that would have been obtained if all the water had been retained in a reservoir and thoroughly mixed before analysis. The time-weighted average is most meaningful from the standpoint of the user who has a constant water demand and where the effect of variable flow is not important.

To meet the overall objectives of the study, the flow-weighted monthly mean TDS concentration was selected as most suitable for the input statistic. These values were obtained or calculated for each month of the period of record for all stations. The monthly mean TDS values through water year 1957 were taken from USGS Professional Paper No. 441 for stations in the Upper Colorado River. For water years 1958 through 1963 and for all stations in the Lower Colorado River Basin, these values were computed from USGS Water Supply Papers and other historical records. It was necessary to synthesize TDS values representing short periods where gaps in the data would have otherwise rendered the record unusable. This was accomplished by the use of flow-quality plots or the TDS-specific conductance ratio.

Specific Analytical Techniques. The analysis of variance and the "Student t Test" which were employed have as one of their basic assumptions the normal distribution of the population to be tested.(6) In nature, few phenomena are characterized by true normal distributions. The reason for this, in many cases, is the impossibility of negative values. Fortunately, moderate departure from normal does not significantly affect the use of more statistical tests which depend upon normal distributions of input data.

Preliminary examination of the data for unregulated streams of the Colorado River Basin revealed bimodal distributions of TDS concentrations. Examples of this type distribution are illustrated in Figures 1

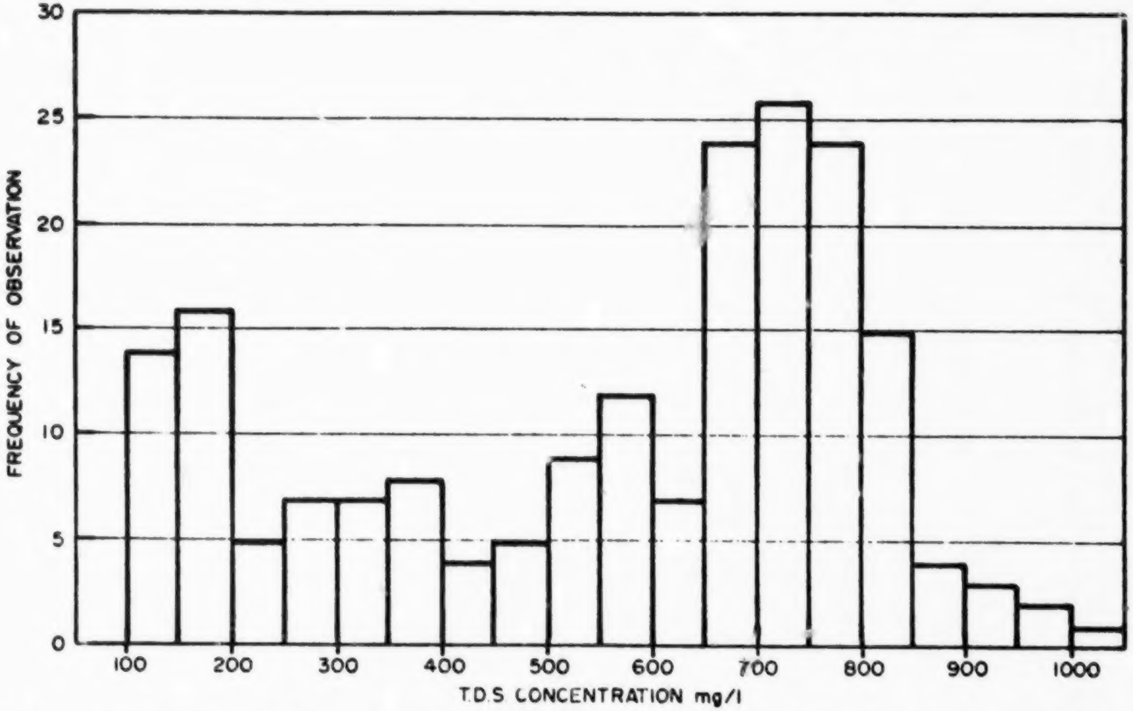

Figure 1 Distribution of Monthly Mean TDS Concentrations for the Eagle River at Gypsum, Colorado

and 2 for the Eagle River at Gypsum, Colorado, and Colorado River near Cisco, Utah. Bimodal distributions, such as those illustrated, indicate that two different populations were sampled. Most of the low TDS concentrations are associated with the high spring runoff flows; whereas TDS values associated with the second peak on the plots are for the low streamflow months.

Examination of the monthly mean discharge data for each of the unregulated streams indicated that the greatest portion of the spring runoff occurred in the months of May and June. The runoff period often extended into April or July, but only rarely to any other month. Therefore, the water quality data for each year were separated into periods of similar flow. The first period included those months associated with the high TDS concentrations, or those months where the streamflow did not include the spring runoff. The months of August through March were found to exclude the spring runoff at all stations included in this study, and are referred to hereafter as the "base flow months." This grouping of monthly TDS data exhibits a nearly normal distribution as shown in Figures 3 and 4. The "base flow" data, then, was found to be suitable for analysis by standard parametric tests including analysis of variance and the "t" test.

The second grouping of TDS concentrations represented the months of April, May, June, and July. A histogram of these values for the Eagle River at Gypsum, Colorado, is presented in Figure 5. It is evident from this plot that the distribution is considerably skewed toward the lower values. At most of the sampling locations studied, April and July are in effect transition months. Their inclusion into either period would

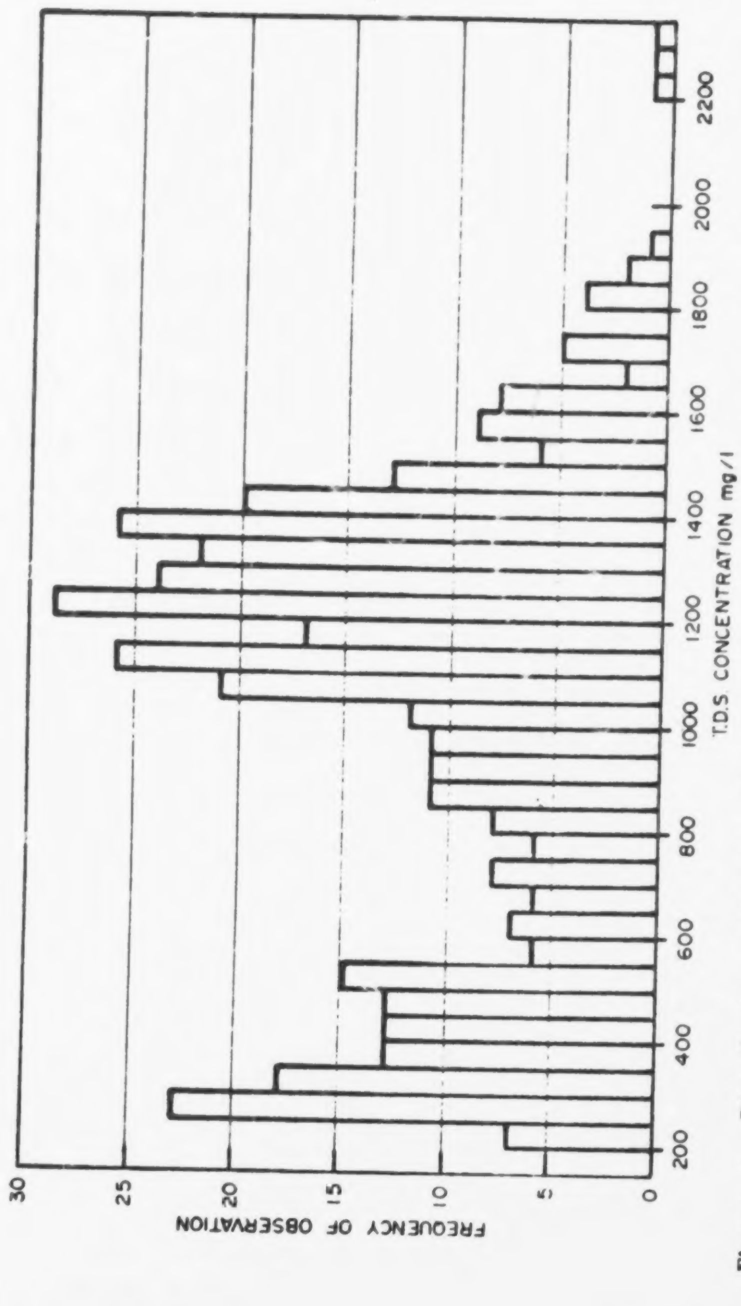

Figure 2 Distribution of Monthly Mean TDS Concentrations for the Colorado River near Cisco, Utah

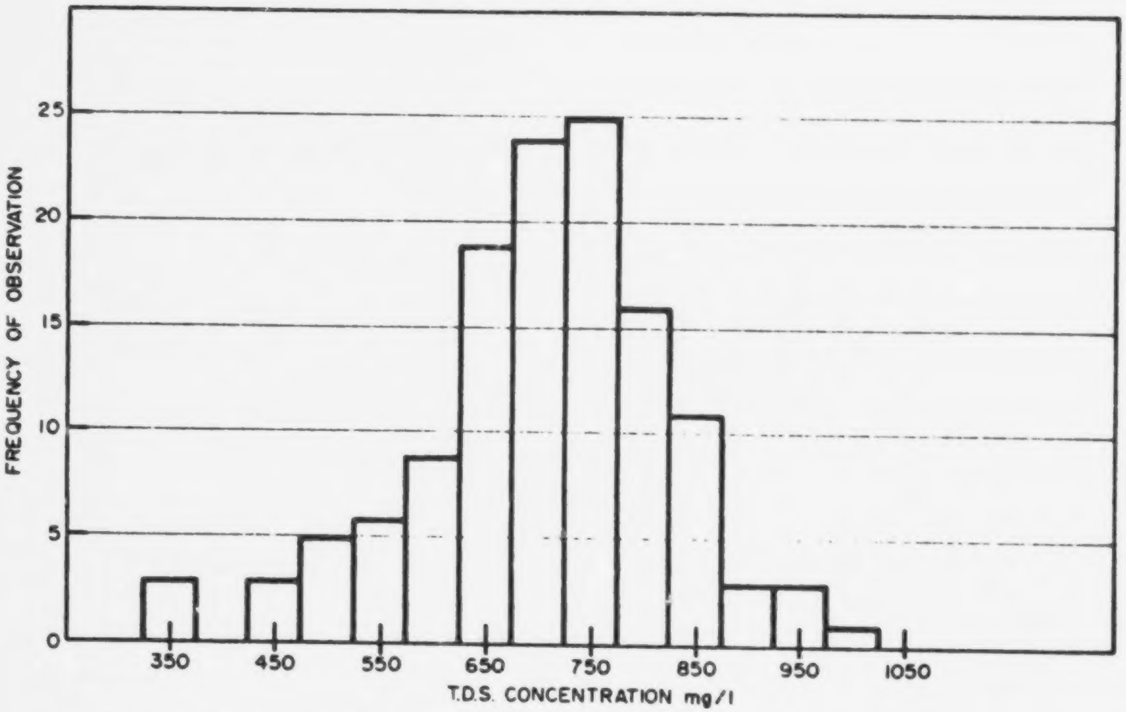

Figure 3 **Distribution of Monthly Mean TDS Concentrations for Base Flow Months for the Eagle River at Gypsum, Colorado**

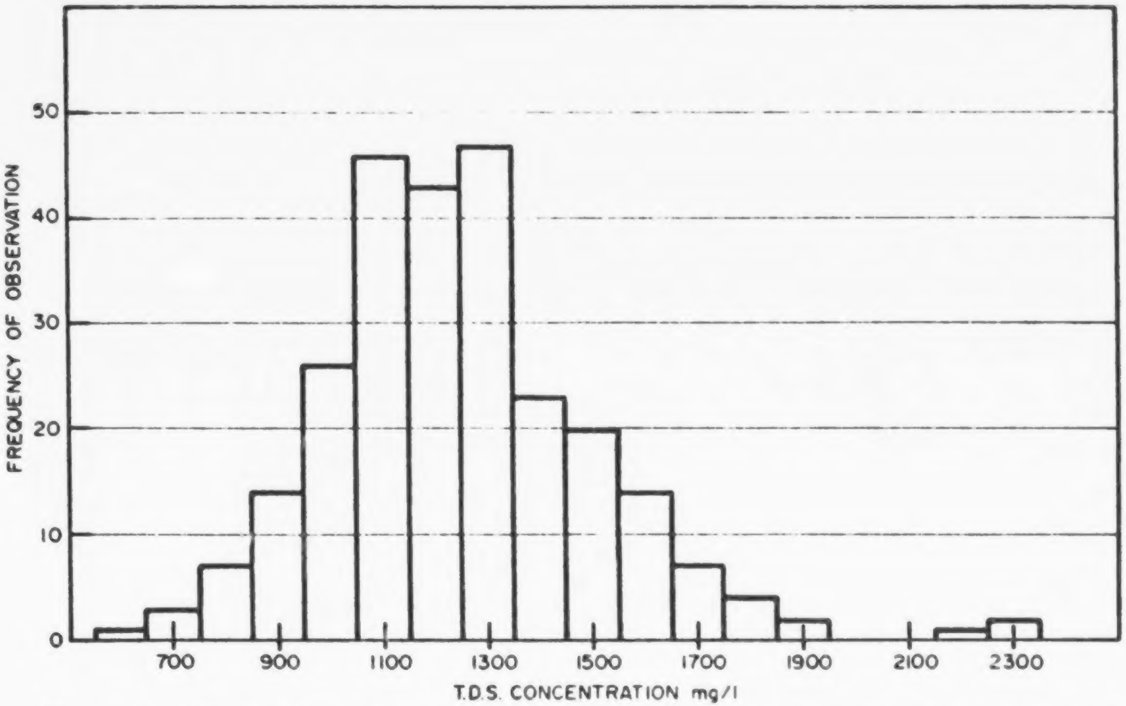

Figure 4 Distribution of Monthly Mean TDS Concentrations for Base Flow Months for the Colorado River near Cisco, Utah

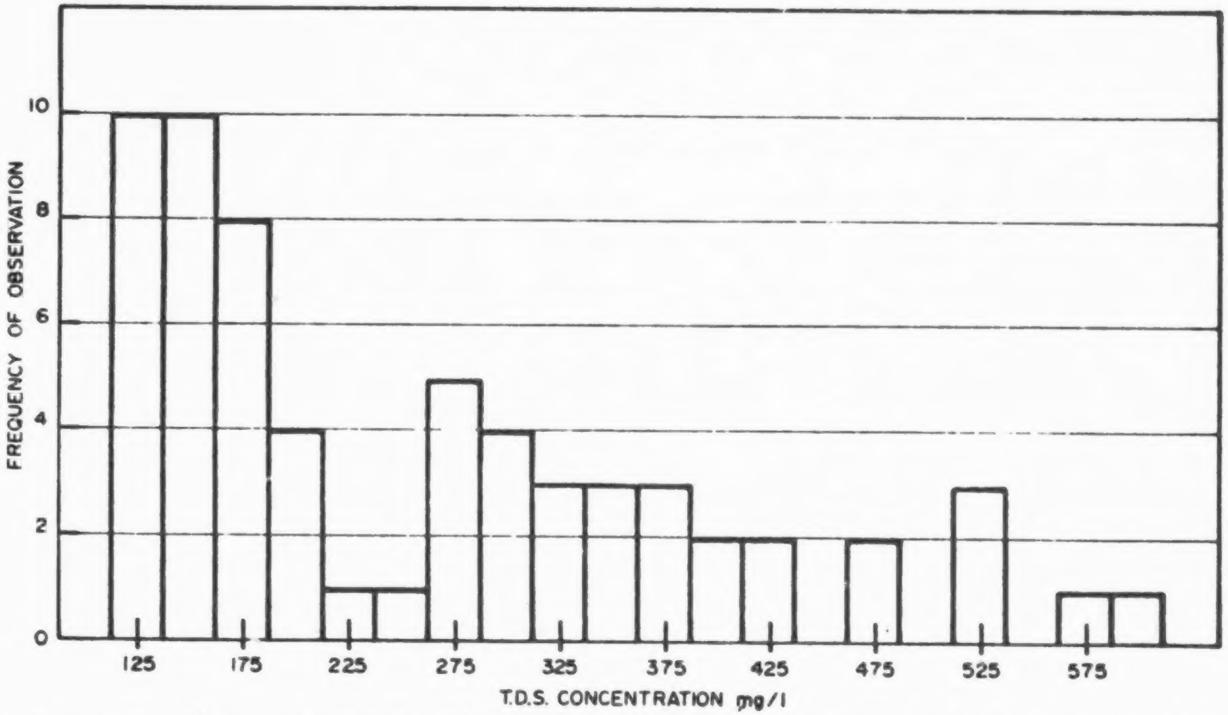

Figure 5 Distribution of Monthly Mean TDS Concentrations for April, May, June, and July for the Eagle River at Gypsum , Colorado

not have presented a true picture of changes that may have occurred. Moreover, the exclusion of the transition months from either the runoff or base flow periods should not affect the detection of changes in quality since any significant change, if present, would have been demonstrated in the two clearly defined periods. Therefore, the data representing the transition months of April and July were not used in the analysis of changes in quality with time, and, for the purposes of this study, May and June were designated as "runoff months."

Histograms of the TDS concentrations during the runoff months are presented in Figures 6 and 7 for the Eagle River at Gypsum, Colorado, and the Colorado River near Cisco, Utah. The distribution of TDS values for the runoff months does not approximate a normal distribution but is skewed toward zero. Parametric tests are not appropriate for analysis of this type of data. Therefore, the median test, a non-parametric method of testing for differences in means was utilized for analysis of data for runoff months.

The classifications described above are only applicable to data for unregulated streams. Streamflow regulation changes the distribution of both flow and concentrations. Because of the large storage capacity of reservoirs, such as Lake Mead, and mixing effects therein, variations within any year of record tend to be considerably dampened. This is illustrated by the distribution of TDS concentrations for the Colorado River at Parker Dam, California-Arizona, for all twelve months as shown in Figure 8. Therefore, data for stations on the main stem of the Colorado River below Lake Mead were analyzed using all twelve months in the same manner as the base flow data for stations in the Upper Colorado River Basin.

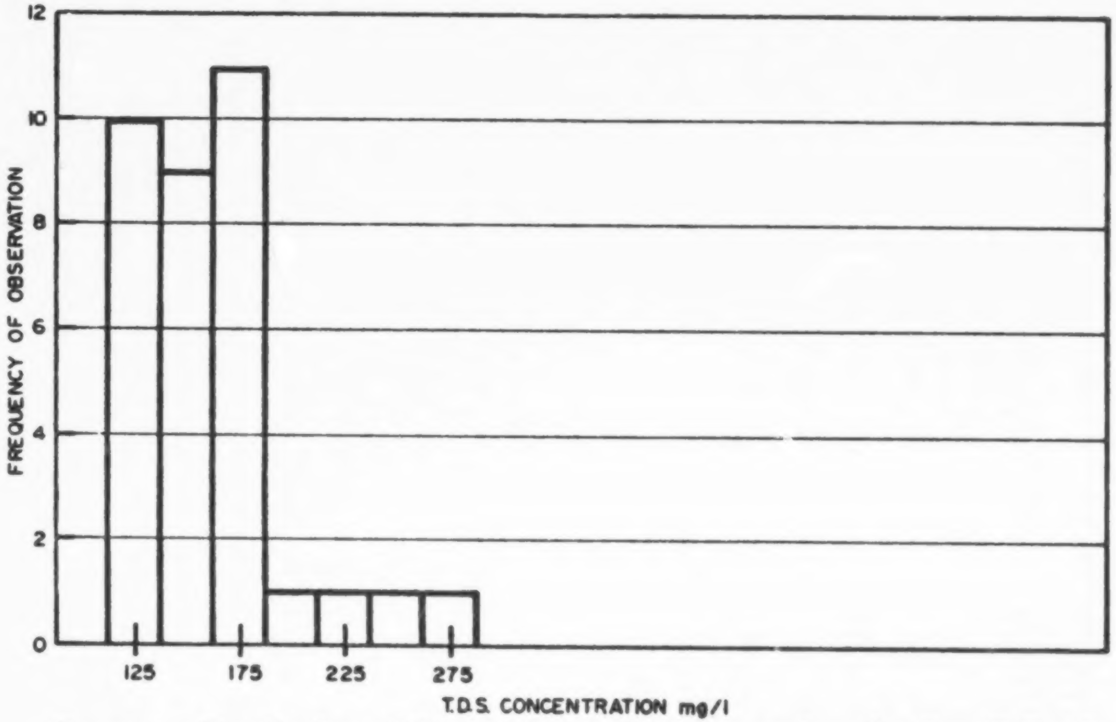

Figure 6 Distribution of Monthly Mean TDS Concentrations for Runoff Months for the Eagle River at Gypsum, Colorado

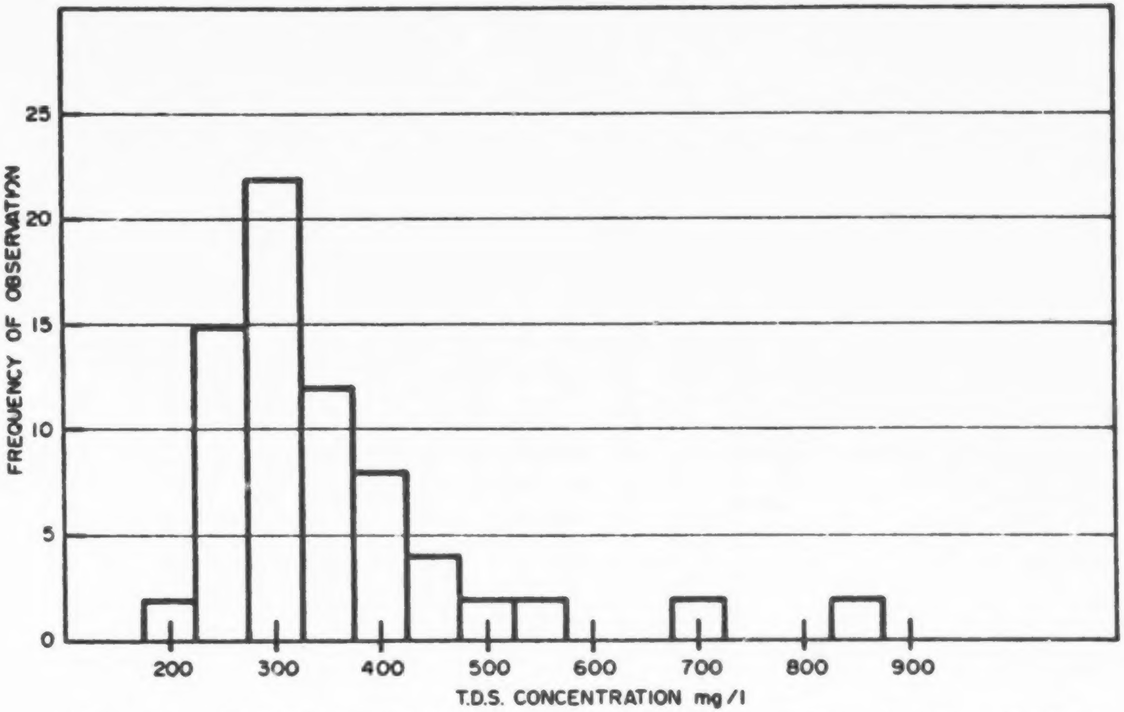

Figure 7 Distribution of Monthly Mean TDS Concentrations for Runoff Months for the Colorado River near Cisco, Utah

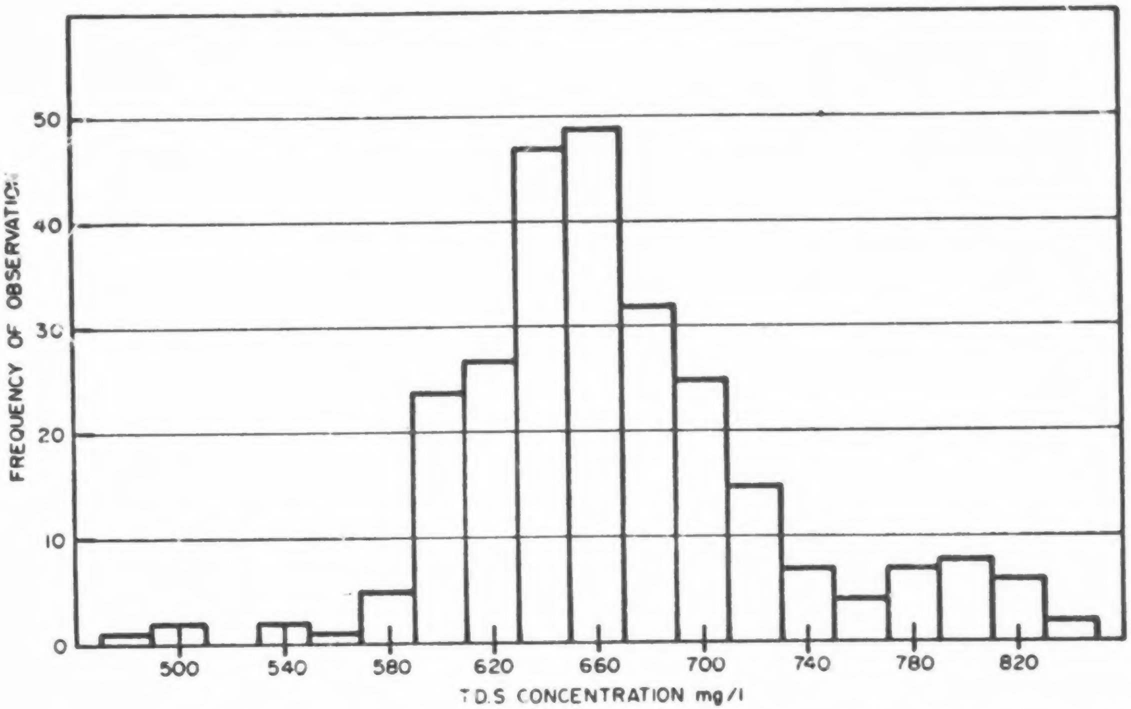

Figure 8 Distribution of Monthly Mean TDS Concentrations for the Colorado River at Parker Dam, California–Arizona

Double Mass Curve(7) techniques were employed to segregate periods of data for testing. In this application of the mass curve technique, the cumulative annual total TDS concentrations for either the runoff or base flow months are plotted against the corresponding years. This causes the time variable to be, in effect, cumulative. If no change in water quality occurred, over the period of record, then the data plots as a straight line and the slope of the line represents the mean concentration for that period. A break in the slope of the TDS mass curve indicates a change in the constant of proportionality between TDS and time, and the position of the break indicates the time at which the change occurred. The change in slope of the line at a break indicates the degree of change in water quality for the two periods.

Cumulative annual totals of the flow-weighted monthly mean TDS concentrations were plotted as percentages of the 1963 water year cumulation. This, in effect, normalized or placed all of the mass curves on a common base. Figure 9 is a typical mass curve of the type utilized in this analysis.[1/]

Mass curves were developed for both the runoff and base flow months on the unregulated streams and for complete years of data on the regulated streams of the Colorado River Basin.

It was necessary to exercise judgment in the selection of breaks representing changes in water quality and to ignore spurious breaks in the

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[1/] All mass curves and other graphical analyses are on file in the Project Offices and are available for examination. The material is of such bulk that its inclusion herein is not practicable. The examples of these graphical techniques, provided herein, are intended to illustrate methods used in the statistical studies.

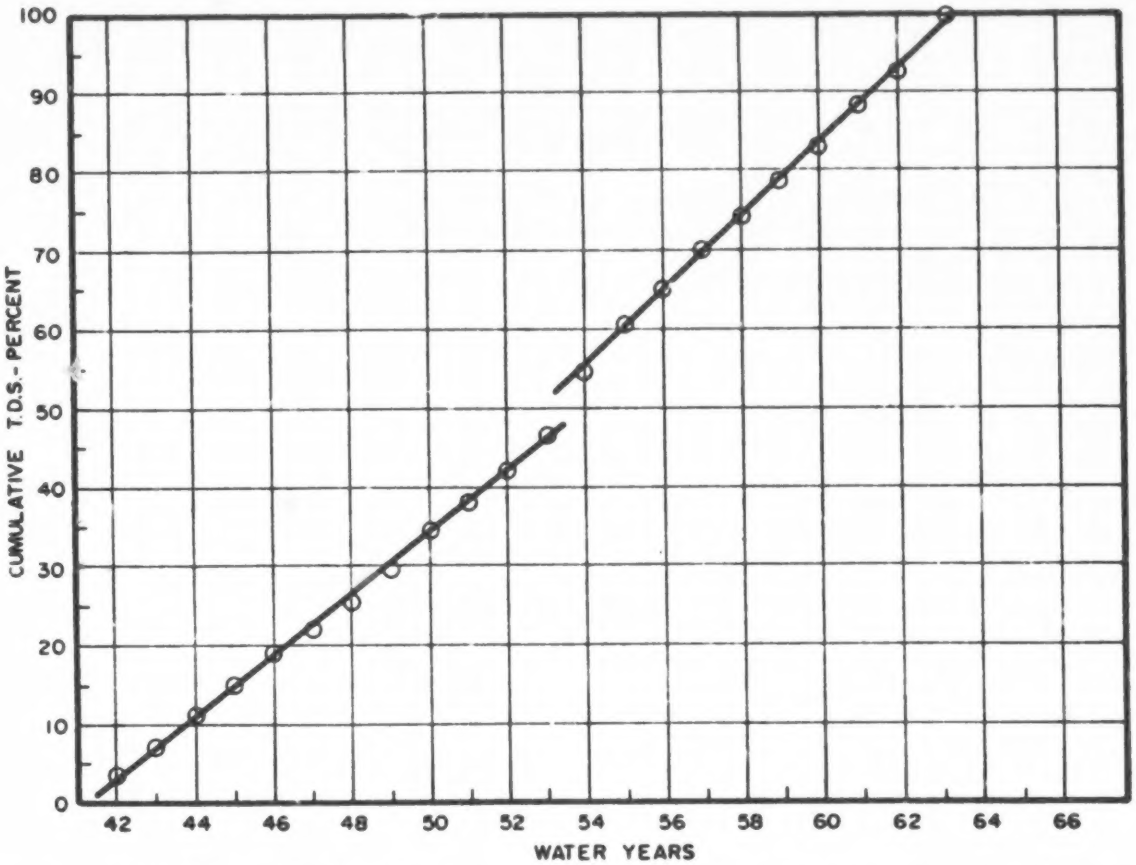


Figure 9 T.D.S. Concentration Mass Curve for the Colorado River near Glenwood Springs, Colorado

curve caused by the inherent variability related to short-term hydrologic patterns. Therefore, only those time periods representing changes of at least five years duration were tested.

In the statistical evaluation of the time patterns, the objective was to determine whether breaks in the mass curves corresponded to statistically significant changes in TDS concentrations. The hypothesis of significant difference between mean concentrations for two periods of time were tested by the "t" test. Since more than two apparent changes were to be tested, at most stations, the analysis of variance, or F-test, was the more appropriate analytical tool.

The F-test compares the variance, s_1^2, of each period tested with the pooled variance, s_2^2. In other words, the F-test is a special case of the "t" test wherein the variances are compared rather than the means. If the same random factors that cause variation within time periods are responsible for observed differences among time period means, then s_1^2 and s_2^2 will be equal within sampling limits. Therefore, the hypothesis tested with the F-test is that $s_1^2 = s_2^2 = \sigma^2$ or that,

$$F = \frac{s_1^2}{s_2^2} = 1$$

Usually the assumption is made that the alternative to $s_1^2 = s_2^2$ is $s_1^2 > s_2^2$, and the one-sided test is used.

The analysis of variance method of testing hypotheses is based upon the following assumptions: (1) that the samples come from a normally distributed parent population, (2) that variances of the populations are equal, (3) that the samples are random, and (4) that in cases of more than one variable of classification the effects are additive. If any of these conditions are not met there is uncertainty in tests of significance, particularly when the variance ratio is very near the critical value.

The assumption of randomness is always questionable in time series data. However, study of runoff for the Colorado River indicated that mean annual runoff can be considered random for periods of five years or more.(8) Since there is a correlation between salinity concentrations and runoff for most unregulated streams in the Colorado River Basin,(2,9) the assumption of randomness is reasonable where means representing periods of five years or more were compared.

The assumption of homogeneous variance was tested by the Bartlett's test which is described in most statistics textbooks.(10) If the populations are not normal, the Bartlett's test is not appropriate since rejection of the hypothesis could mean that the population variances are unequal and that the populations are not normal, or both. However, since this test is very sensitive to normality, acceptance of the hypothesis of equal variances also indicates that the data approximates a normal distribution.

The median test was utilized for the base flow months at those stations where the assumptions of normality and homogeneous variance were not satisfied. The number of cases in two samples, of size N_1 and N_2, falling above and below the median of the combined observations, $N = N_1 + N_2$, can be used to test the hypothesis that the samples are randomly drawn from two identically distributed populations. This test can be expanded for any number of samples and is not dependent upon normal distribution or homogeneous variances.

In cases where changes in quality appeared to be associated with changes in streamflow, three techniques were employed to confirm their association:

(1) Mass curve for stream discharge using a five-year moving average. This curve illustrates any change in trend in the runoff pattern with respect to time at each station. A five-year moving average was used to minimize the large variation in annual means which was exhibited at a number of stations.

(2) Percent of average flow graphs. The mean flow was calculated for the period of record for each station, and then the average flow for each year was converted to percentage of the mean flow for the period of record. These percentages were plotted on the TDS mass curves. Those years having greater than average annual streamflow for the period of record are represented by the area above the TDS mass curve line. The area bleow the mass curve indicates deficient runoff. Figure 10 illustrates the percent of average flow plots utilized in this technique.

(3) Spearman's Rank Correlation Coefficient.(6) This is a non-parametric test to determine the degree of correlation between two variables when the observations are taken at the same time. It is similar to the correlation coefficient of the least squares technique. It has been shown that most unregulated streams exhibit some flow-quality relationship. If a change in quality was due to a change in climatic conditions, then a flow-quality relationship should have prevailed during the period examined.

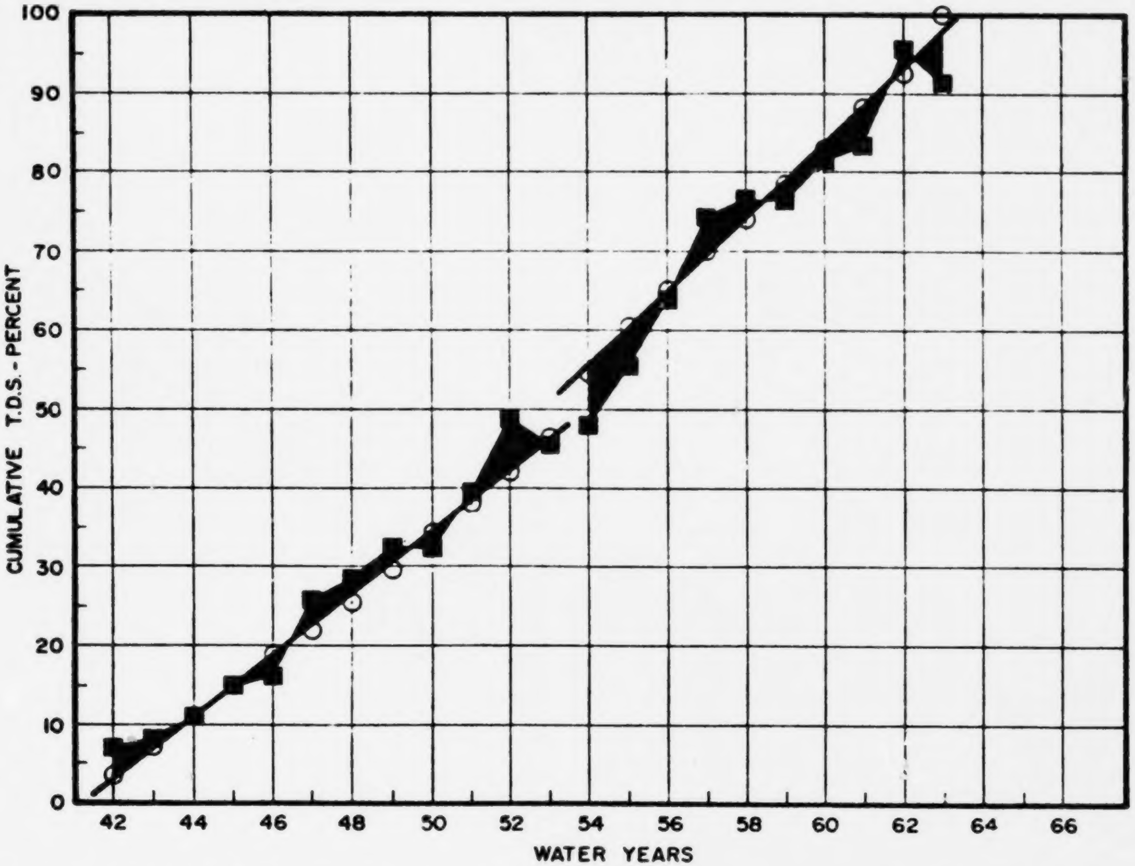


Figure 10 TDS Concentration Mass Curve and Percent Average Flow for May and June, for the Colorado River near Glenwood Springs, Colorado

Testing for significant changes in water quality, with respect to time, for the runoff months at each station was accomplished in a manner similar to that used for the base flow months. The major difference was in the use and interpretation of the analysis of variance since the assumptions of normality and homogeneity of variance could not be satisfied. The non-parametric median test was used as the statistical basis for decisions on the acceptance or rejection of the hypotheses of equal means for the time periods being considered.

The same procedures that were employed for the base flow months were followed in determining the causes of significant changes for the runoff months.

Results of Time Analyses

The time studies revealed that significant changes in mineral quality of Colorado River Basin streams, above Hoover Dam, occurred at eleven locations, during base flow months and at five locations during runoff months. Increases in mineral concentrations during base flow months were detected for the Colorado River at Hot Sulphur Springs, at Lees Ferry and at Grand Canyon; the Animas River at Farmington, New Mexico; and the San Juan River near Bluff, Utah. Statistically significant decreases in mineral concentrations were detected for the Colorado River near Cameo, Colorado, near Cisco, Utah, and Grand Canyon, Arizona; the Gunnison River near Grand Junction, Colorado; the White River near Watson, Utah; and the San Rafael River near Green River, Utah.

Increases in mineral concentrations during runoff months occurred for the Colorado River at Hot Sulphur Springs, Colorado, near Glenwood Springs, Colorado, near Cameo, Colorado, and near Cisco, Utah. No statistically significant decreases in mineral concentrations were detected during runoff months at Upper Colorado River Basin sampling stations.

All of the changes detected were definitely associated with changes in streamflow but only the 22 mg/l increase in TDS concentration for the Colorado River at Hot Sulphur Springs could clearly be associated with man-caused changes in flow. Closure of Willow Creek Dam of the Colorado-Big Thompson Project coincided with this increase.

All stations downstream of Hoover Dam exhibited statistically significant increases in mineral concentrations. These increases were associated with the drought of the mid-1950's, introduction of and subsequent improvements in the drainage of irrigated lands, the closure of dams and increased consumptive use. Decreases in mineral concentrations were detected at all stations below Hoover Dam at the conclusion of the drought.

Results of the time analyses are summarized in Tables 1, 2, and 3. Detailed discussions of these analyses are available in an open file report at the Project Office(11).

CHANGES IN WATER QUALITY WITH RESPECT TO DISTANCE

The objective of the distance analysis was to ascertain the significance of changes in mineral quality between sampling locations on streams in the Colorado River Basin. The study was also intended to single out reaches of streams in which significant increases in TDS concentrations occur. Such reaches would then be studied on a more intensive basis to identify the sources of salinity.

A

Table 1. Changes in Water Quality at Sampling Stations in the C
Above Hoover Dam During the Base Flow Months (A

Station Location	Period of Years		TDS Mean for Period (mg/l)	Analysis of Variance		Bartlett's Test	
	From	To		Observed F Value	Critical F Value 95%	Observed F Value	Critical F Value 95%
Colorado River at Hot Sulphur Springs, Colorado	48	53	85	41.46	3.92	2.09	3.84
	54	63	93				
Eagle River at Gypsum, Colorado	48	58	720	3.20	3.92	2.29	3.84
	59	63	679				
Colorado River near Glenwood Springs, Colorado	42	54	436	0.26	3.84	0.67	3.84
	55	63	430				
Colorado River near Cameo, Colorado	34	44	793	43.96	3.84	2.64	3.84
	45	63	698				
Gunnison River near Grand Junction, Colorado	32	40	1,530	30.18	3.84	21.54	3.84
	41	63	1,290				
Dolores River near Cisco, Utah	52	63	2,250	Variable - no 5-year trends			
Colorado River near Cisco, Utah	29	30	1,090	Not included in significance test			
	31	44	1,370	29.72	3.84	2.70	3.84
	45	63	1,210				
San Juan River near Archuleta New Mexico	56	63	263	Insufficient record			
Animas River at Farmington, New Mexico	41	50	471	32.27	3.84	6.11	3.84
	51	63	559				
San Juan River near Bluff, Utah	30	50	757	19.89	3.84	0.55	3.84
	51	63	841				
Green River near Green River, Wyoming	52	58	477	3.20	4.00	0.09	3.84
	59	63	441				
Henry's Fork at Linwood, Utah	52	56	1,235	0.26	4.00	2.45	3.84
	56	63	1,193				
Green River near Greendale, Utah	57	63	552	Insufficient record			
Yampa River near Maybell, Colo.	51	63	311	Straight line on Mass Curve			
Little Snake River near Lily, Colorado	51	56	532	0.13	3.92	2.00	3.84
	57	63	516				

B

Sampling Stations in the Colorado River Basin
ing the Base Flow Months (August-March)

Bartlett's Test		Median		Rank Correlation Coefficient Flow x Quality	Probable Cause of Change or Remarks
Observed F Value	Critical F Value 95%	Observed χ^2	Critical χ^2-95%		
2.09	3.84			+0.05 -0.18	Willow Creek Dam of the Colorado-Big Thompson Project
2.29	3.84			-0.59	No change
0.67	3.84			-0.77	No change
2.64	3.84			-0.85	Drought of the 1930's
21.54	3.84	16.25	3.84	-0.36	Drought of the 1930's
trends					No change
ficance test					
2.70	3.84			-0.61 -0.70	Drought of the 1930's
					Insufficient record
6.11	3.84	27.09	3.84	-0.85 -0.83	Below average streamflow
0.55	3.84			-0.70	Below average streamflow
0.09	3.84				No change
2.45	3.84				No change
					Insufficient record
Curve					No change
2.00	3.84				No change

A

Table 1. Contd. Changes in Water Quality at Sampling Station
Above Hoover Dam During the Base Flow

	Period of Years		TDS Mean for Period (mg/l)	Analysis of Variance		Bartlett's Test	
Station Location	From	To		Observed F Value	Critical F Value 95%	Observed F Value	Critical F Value 9
Duchesne River near Randlett, Utah	57	63	1,310	Insufficient record			
White River near Watson, Utah	51	57	622	4.33	3.92	1.98	3.84
	58	63	597				
Green River near Ouray, Utah	57	63	593	Insufficient record			
Price River at Woodside, Utah	52	63	3,990	Straight line on Mass Curve			
Green River at Green River, Utah	29	36	693	7.56	3.00	21.79	3.00
	37	46	753				
	47	63	709				
San Rafael River near Green River, Utah	48	57	3,151	4.86	3.92	1.05	3.84
	(less 1950)						
	58	63	2,863				
Colorado River at Lees Ferry, Arizona	48	53	965	4.88	3.92	5.46	3.84
	54	63	1,020				
Colorado River near Grand Canyon, Arizona	26	33	1,020	6.83	2.99	4.75	2.99
	34	41	1,130				
	42	63	1,060				

ty at Sampling Stations in the Colorado River Basin
m During the Base Flow Months (August-March)

e %	Bartlett's Test Observed F Value	Bartlett's Test Critical F Value 95%	Median Observed χ^2	Median Critical χ^2-95%	Rank Correlation Coefficient Flow & Quality	Probable Cause of Change or Remarks
rd						No Change
	1.98	3.84			-0.41	Drought of mid-1950's
rd						Insufficient record
ass Curve						No change
					-0.45	
	21.79	3.00			-0.46	
			14.86	5.99	-0.49	
					-0.77	Drought of mid-1950's
	1.05	3.84				
					-0.75	
	5.46	3.84			-0.73	Drought of mid-1950's
					-0.49	
	4.75	2.99	5.34	5.99 4.61(90%)	-0.71	Drought of mid-1930's

A.

Table 2. Changes in Water Qual
Above Hoove

	Period Of Years		TDS Mean for Period	Analysis of Variance	
Station Location	From	To	(mg/l)	Observed F Value	Critical F Value 95
Colorado River at Hot Sulphur Springs, Colorado	48	52	56	23.14	4.17
	53	63	78		
Eagle River at Gypsum, Colorado	48	53	154	0.70	4.17
	54	63	165		
Colorado River near Glenwood Springs, Colorado	42	53	155	18.00	4.07
	54	63	212		
Colorado River near Cameo, Colorado	34	53	226	10.75	4.00
	54	63	274		
Gunnison River near Grand Junction, Colorado	34	53	372	4.15	4.00
	54	63	439		
Dolores River near Cisco, Utah	52	63	400		
Colorado River near Cisco, Utah	29	53	329	5.06	3.99
	54	63	395		
San Juan River near Archuleta, New Mexico	56	63	119		
Animas River at Farmington, New Mexico	41	49	163	6.53	4.08
	50	63	193		
San Juan River near Bluff, Utah	30	63	271		
Green River near Green River, Wyoming	52	58	244	0.57	4.26
	59	63	265		
Henry's Fork at Linwood, Utah	52	63	663		
Green River near Greendale, Utah	57	63	374		
Yampa River near Maybell, Colorado	51	56	106	1.24	4.26
	57	63	116		

B

Table 2. Changes in Water Quality at Sampling Stations in the Colorado River Basin Above Hoover Dam During the Runoff Months (May & June)

TDS Mean for Period (mg/l)	Analysis of Variance		Median		Rank Correlation Coefficient Flow & Quality	Probable Cause of Change or Remarks
	Observed F Value	Critical F Value 95%	Observed χ^2	Critical χ^2-95%		
56 78	23.14	4.17	11.78	3.84	-0.81 -0.66	Willow Creek Dam of the Colorado-Big Thompson Proj.
154 165	0.70	4.17	0.13	3.84	-0.78	No change
155 212	18.00	4.07	15.49	3.84	-0.76 -0.88	Drought of mid-1950's
226 274	10.75	4.00	3.68	3.84 (2.71)	-0.81	Drought of mid-1950's
372 439	4.15	4.00	0.08	3.84	-0.89	No change
400						No change
329 395	5.06	3.99	3.43	3.84 (2.71)	-0.89	Drought of mid-1950's
119						No change
163 193	6.53	4.08	4.47	3.84	-0.46 -0.90	Below average streamflow
271						No change
244 265	0.57	4.26	0.17	3.84	-0.74	No change
663						No change
374						Insufficient record
106 116	1.24	4.26	0.16	3.84	+0.22	No change

A

Table 2. Contd. Changes in Water Quality at Sampling Stations in
Above Hoover Dam During the Runoff Mont

Station Location	Period of Years		TDS Mean for Period	Analysis of Variance		Median		Rank Co Coeff
	From	To	(mg/1)	Observed F Value	Critical F Value 95%	Observed χ^2	Critical χ^2-95%	Flow &
Little Snake River near Lily, Colorado	51	55	161	2.21	4.26	0.16	3.84	-0.
	56	63	147					
Duchesne River near Randlett, Utah	57	63	849					
White River near Watson, Utah	51	56	339	0.43	4.26	0.16	3.84	-0.
	57	63	321					
Green River near Ouray, Utah	57	63	247					
Price River at Woodside, Utah	53	57	3,084	2.43	4.35	1.65	3.84	-0.
	58	63	4,126					
Green River at Green River, Utah	29	40	290	3.10	3.15	1.30	5.99	-0.
	41	55	308					
	56	63	276					
San Rafael River near Green River, Utah	58	63	1,590					
Colorado River at Lees Ferry, Arizona	48	53	321	3.05	4.17	3.47	3.84	-0.
	54	62	366					
Colorado River near Grand Canyon, Arizona	26	52	355	5.08	4.00	0.07	3.84	-0.
	53	62	403					

ges in Water Quality at Sampling Stations in the Colorado River Basin
Above Hoover Dam During the Runoff Months (May & June)

s of Variance	Median		Rank Correlation Coefficient	
Critical F Value 95%	Observed χ^2	Critical χ^2-95%	Flow & Quality	Probable Cause of Change or Remarks
4.26	0.16	3.84	-0.17	No change
				Insufficient record
4.26	0.16	3.84	-0.21	No change
				Insufficient record
4.35	1.65	3.84	-0.93	No change
3.15	1.30	5.99	-0.30	No change
				No change
4.17	3.47	3.84	-0.85	No change Closure of Glen Canyon Dam
4.00	0.07	3.84	-0.80	No change Closure of Glen Canyon Dam

A

Table 3. Changes in Water Quality at Sampling Stations in t
of the Colorado River Below Hoover

tation Location	Period of Years		TDS Mean for Period (mg/l)	Analysis of Variance		Bartlett's Test		Ob
	From	To		Observed F Value	Critical F Value 95%	Observed F Value	Critical F Value 95%	
Colorado River below Hoover Dam	36	42	712	18.46	3.00	102.1	3.00	
	43	54	660					
	58	63	675					
	55	57	801	Not included in significance test				
	43	54	660	26.22	3.84	1.51	3.84	
	58	63	675					
olorado River at Parker Dam, Arizona-California	42	48	672	31.96	3.00	9.47	3.00	
	49	54	624					
	58	63	657					
	55	57	771	Not included in significance test				
	49	54	624	23.76	3.84	0.07	3.84	
	58	63	657					
olorado River at Imperial Dam, Arizona-California	45	54	690	244.15	3.84	0.28	3.84	
	58	63	787					
	55	57	876	Not included in significance test				
olorado River at Yuma, Arizona	27	34	930					
	35	39	781					
	40	49	731					
	50	54	676					
	55	57	880					
	58	60	779					
	61	63	2,238					
	40	49	731	32.82	3.84	5.08		
	50	54	676					

B

ty at Sampling Stations in the Lower Main Stem
Colorado River Below Hoover Dam

	Bartlett's Test		Median		Rank Correlation Coefficient	Probable Cause of Change or Remarks
	Observed F Value	Critical F Value 95%	Observed χ^2	Critical χ^2-95%	Flow & Quality	
					-0.05	Filling period of Lake Mead
	102.1	3.00			-0.09	
					-0.07	Drought of mid-1950's and low level of Lake Mead
nificance test					-0.12	
	1.51	3.84			-0.09	
					-0.07	
					+0.10	
	9.47	3.00			-0.10	Closure of Davis Dam
					-0.13	Drought of mid-1950's and low level of Lake Mead
nificance test					-0.47	
	0.07	3.84			-0.10	
					-0.13	
	0.28	3.84			-0.37	Cessation of drought and drainage facilities at CRIR and PVID
					-0.53	Drought of mid-1950's and low level of Lake Mead
nificance test						
						Prior to Hoover Dam
						Closure of Hoover, Parker, Imperial Dams, complete diversion of Gila River and MWD Aqueduct
						Equilibrium period
						Completion of Davis Dam
						Drought of mid-1950's and low level of Lake Mead
						Cessation of drought and increased drainage at CRIR and PVID
						Wellton-Mohawk drainage
	5.08					

In the study of the distance patterns, the five years of record immediately prior to water year 1964 were used in determining mean TDS concentrations. The five-year period was selected in order that the influences of wet and dry years might be eliminated and to assure that the data would be as nearly homogeneous as possible. The water quality data used in this portion of the study were grouped as "base flow" and "runoff months" in the same manner as in the time analysis.

The approach taken, in the distance pattern analysis, was somewhat different from that taken by Iorns, et al(4) in that no synthesized data were utilized and a uniform five-year time span was employed. These constraints were imposed in order to minimize the effects of climatological cycles and the non-uniform pattern of man's developmental activities in the Basin. Minor differences in qualitative results of Iorns' analysis and the Project are apparent; however, the results of both analyses lead to the same conclusions regarding distance patterns in the Upper Colorado River Basin. Iorns did not undertake a similar analysis in the Lower Basin.

Data representing sequential pairs of stations were subjected to analysis by parametric and non-parametric tests. The TDS mean concentrations for all stations on the Lower Colorado River differed significantly at the 95 percent confidence level. Even the 29 mg/l difference in mean TDS concentration for the runoff months between Lees Ferry and Grand Canyon was found to be highly significant.

The mean TDS concentrations at key stations on streams in the Colorado River Basin are presented in Table 4. The difference in concentrations for adjacent stations is obvious in most cases. The

Table 4. Mean TDS Concentrations for Key Stations in the Colorado River Basin Water Years 1959-1963

River	Location of Station	Base Months (mg/l)	All Months (mg/l)	Runoff Months (mg/l)
Colorado	Hot Sulphur Springs, Colo.	94		77
	Glenwood Springs, Colo.	402		208
	Cameo, Colorado	732		265
	Cisco, Utah	1,152		316
	Lees Ferry, Arizona	1,015		477(372)[a]
	Grand Canyon, Arizona	1,069		512(401)
	Hoover Dam, Arizona-Nevada		677	
	Imperial Dam, Arizona-Calif.		792	
	Yuma, Arizona		Changing	
San Juan	Archuleta, New Mexico	259		124
	Bluff, Utah	869		316
Green	Green River, Wyoming	441		265
	Greendale, Utah	557(533)		407(337) [a]
	Ouray, Utah	592		240
	Green River, Utah	722		276
Eagle	Gypsum, Colorado	679		156
Gunnison	Grand Junction, Colorado	1,220		408
Dolores	Cisco, Utah	2,140		464
Animas	Farmington, New Mexico	552		203
Henry's Fork	Linwood, Utah	1,200		615
Yampa	Maybell, Colorado	317		112
Little Snake	Lily, Colorado	532		147
Duchesne	Randlett, Utah	1,220		999
White	Watson, Utah	601		303
Price	Woodside, Utah	3,950		4,740
San Rafael	Green River, Utah	722		276

---

[a] Figures in parentheses are for water years 1959-62. Closure of Glen Canyon and Flaming Gorge Dams caused abnormally high TDS concentrations at downstream stations in 1963.

dendritic diagrams for the runoff months (Figure 11) and the base flow months (Figure 12) show the changes in mineral quality with respect to distance for streams above Lake Mead. The relationships between quality changes and distance for sampling locations downstream of Hoover Dam are shown in Figure 13. Increases in TDS concentration occur, generally, in progression downstream, except where inputs of higher quality water dilute the water in the receiving streams. Increases are most marked in those reaches where agricultural drainage exerts strong influence and where overland runoff contributes dissolved salts to the streams. Causes of changes in water quality, with respect to distance, are discussed in detail in Chapter IV of this Appendix.

SUMMARY OF FINDINGS

During base flow months (August through March), four stations located above Hoover Dam exhibited increases in TDS concentrations, four showed decreases, and two experienced both increases and decreases. TDS concentrations increased significantly at five stations above Hoover Dam during runoff months. There were no cases of statistically significant decreases in salinity during the runoff months at these stations. All of the Colorado River stations downstream of Hoover Dam showed both increases and decreases in TDS concentrations.

All of the changes in quality in the Colorado River Basin at stations above Hoover Dam were associated with changes in the streamflow. Only one of these changes in streamflow could be clearly associated with man's activities. Closure of Willow Creek Dam was associated with increases in TDS concentrations at downstream stations. Other changes appeared to be the result of drought periods of the early and middle 1930's and mid-1950's.

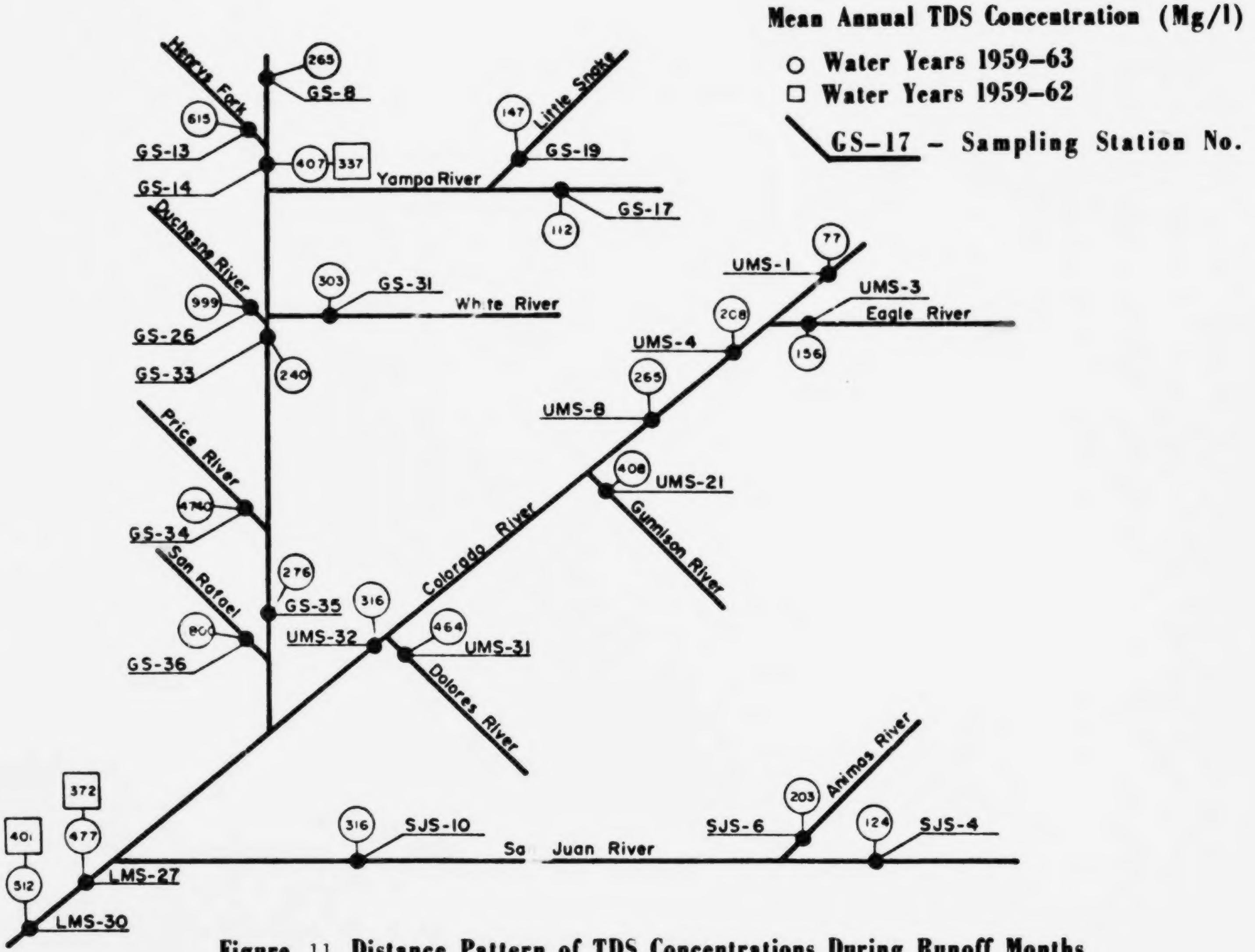

Mean Annual TDS Concentration (Mg/l)
○ Water Years 1959–63
□ Water Years 1959–62
GS–17 – Sampling Station No.
Henrys Fork
265
GS-8
615
GS-13
407
337
GS-14
Yampa River
147
Little Snake
GS-19
112
GS-17
Duchesne River
999
GS-26
303
GS-31
White River
240
GS-33
Price River
4740
GS-34
San Rafael
800
GS-36
276
GS-35
316
UMS-32
464
UMS-31
Dolores River
Colorado River
408
UMS-21
Gunnison River
265
UMS-8
208
UMS-4
77
UMS-1
UMS-3
Eagle River
156
372
477
LMS-27
401
512
LMS-30
316
SJS-10
San Juan River
203
SJS-6
Animas River
124
SJS-4

Figure 11 Distance Pattern of TDS Concentrations During Runoff Months for the Colorado River & Tributaries above Lake Mead

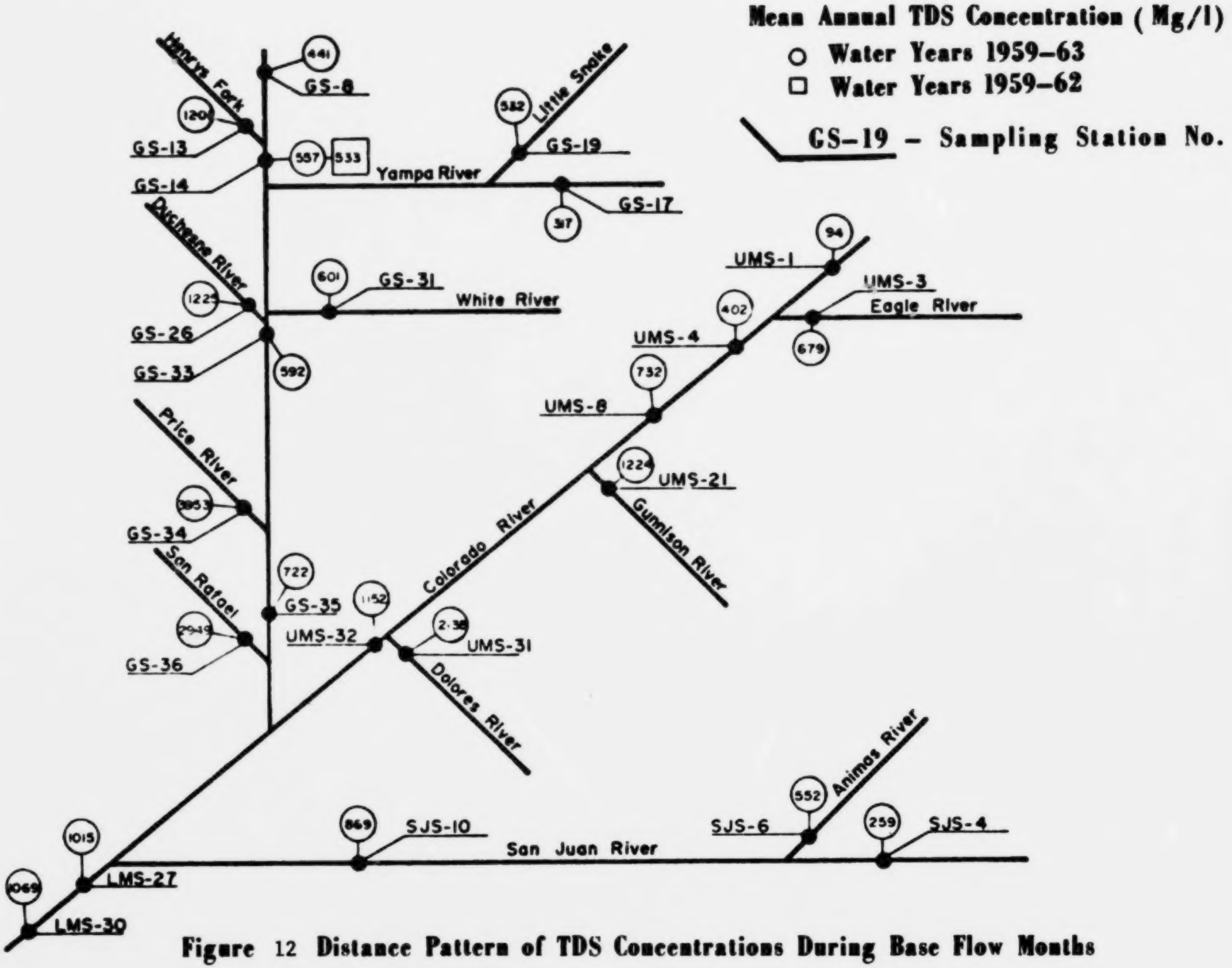

Mean Annual TDS Concentration (Mg/l)
○ Water Years 1959–63
□ Water Years 1959–62
GS–19 – Sampling Station No.
Henrys Fork
441
GS-8
1201
GS-13
557
533
GS-14
Yampa River
582
Little Snake
GS-19
317
GS-17
Duchesne River
1225
GS-26
601
GS-31
White River
592
GS-33
Price River
3853
GS-34
San Rafael
2949
GS-36
722
GS-35
1152
UMS-32
Colorado River
2.38
UMS-31
Dolores River
1224
UMS-21
Gunnison River
732
UMS-8
402
UMS-4
94
UMS-1
UMS-3
Eagle River
679
1015
LMS-27
1069
LMS-30
869
SJS-10
San Juan River
552
SJS-6
Animas River
259
SJS-4

Figure 12 Distance Pattern of TDS Concentrations During Base Flow Months for the Colorado River & Tributaries above Lake Mead

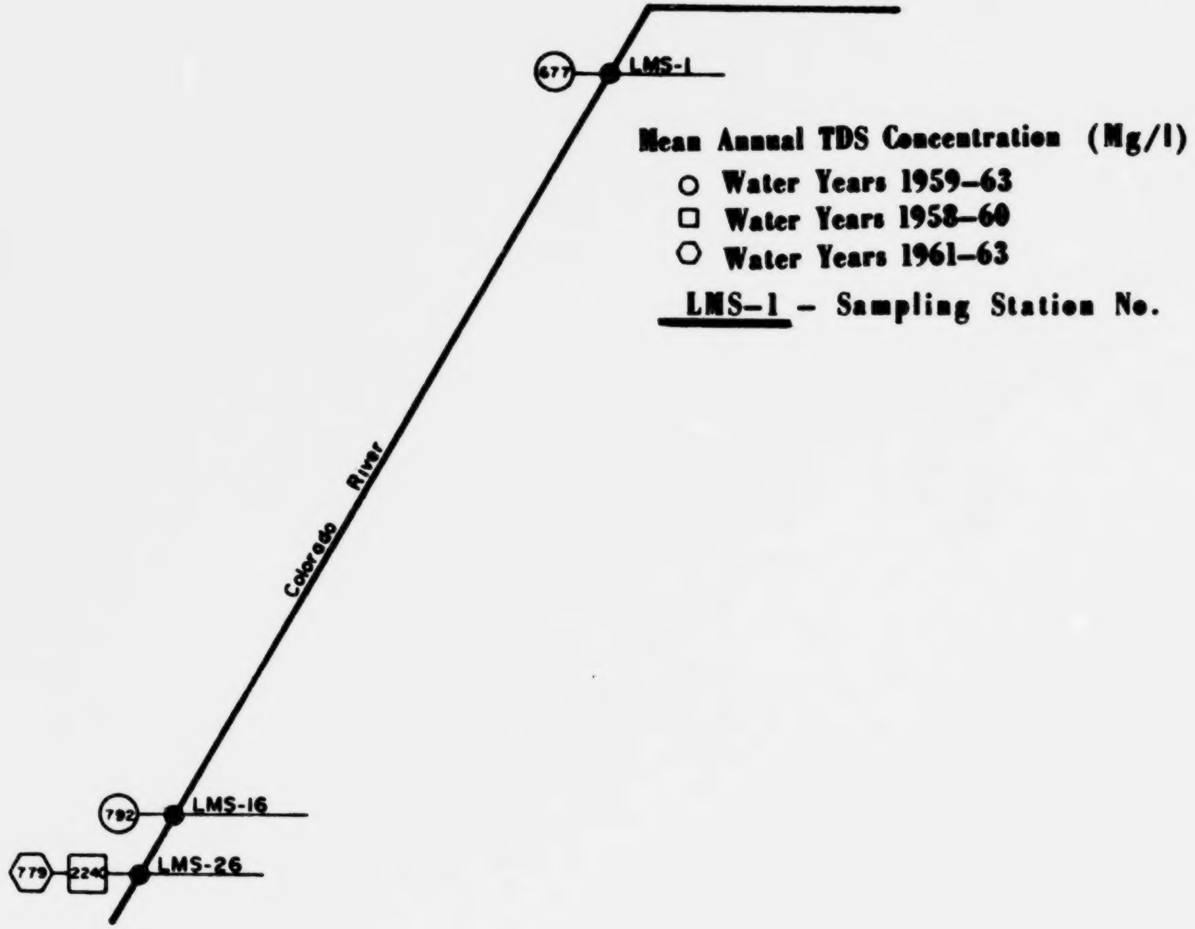

677
LMS-1
Mean Annual TDS Concentration (Mg/l)
○ Water Years 1959–63
□ Water Years 1958–60
⬡ Water Years 1961–63
LMS–1 – Sampling Station No.
Colorado River
792
LMS-16
779
2240
LMS-26

Figure 13 Distance Pattern of TDS Concentrations for the Colorado River below Hoover Dam

Changes in quality of the waters of the Colorado River downstream of Hoover Dam were found to be associated both with changes in streamflow and with the drainage from irrigated areas.

Analyses of the changes in water quality with respect to distance affirm that increases in TDS concentrations occur generally in downstream sequence, except where inputs of higher quality water dilute the water in the receiving streams. Increases are most marked in those reaches where agricultural drainage exerts strong influence and where overland runoff contributes dissolved salts to the streams.

CHAPTER IV. NATURE, LOCATION, AND MAGNITUDE OF SALINITY SOURCES

Several studies of mineral quality of water have been carried out in the Colorado River Basin. These include investigations by LaRue,(12) the U. S. Geological Survey,(4) and the Bureau of Reclamation.(13) These studies were based largely on existing water quality data, but incorporated the findings of special field studies in certain problem areas. Several Federal agencies, including the Bureau of Reclamation and the Geological Survey, have maintained long-term water quality surveillance programs, of varying intensity and techniques, throughout the Basin.

A detailed review of publications, reports, and unpublished information, by the Project staff, indicated certain gaps in existing data on mineral quality of the Basin's waters that needed to be filled in order to evaluate the changes in quality for certain reaches of streams. The Project, therefore, carried out short-term sampling programs and field investigations throughout the Basin to obtain data needed to fill major gaps in existing water data and to obtain detailed information on the location and magnitude of salinity sources. The Project studies included:

1. Detailed and intensive map and ground reconnaissance of the Colorado River Basin.
2. Study of geohydrology and stratigraphy of the Basin, and their effects on mineral quality of streams.
3. Evaluation of the effects of springs, seeps, diffuse natural sources, overland runoff, municipal and industrial discharges, and irrigation on mineral quality of streams.

4. Stream sampling and flow measurements to define stream reaches in which major changes in salinity and mineral composition occur.
5. Intensive water and salt budget studies of individual watersheds in the Upper Colorado River Basin, and of major irrigated areas adjacent to the Lower Main Stem of the Colorado River.

The studies were carried out in the Lower Colorado River Basin during the period November 1963 through December 1964, and in the Upper Basin from June 1965 through May 1966. The upper portions of the Little Colorado and Gila River drainage areas were not included in the studies since literature review and study of hydrological records indicated that these areas contribute insignificant amounts of flow and salt load to the Lower Colorado River. Except during infrequent floods, the Gila River has been discontinuous at Gillespie Dam since 1937. The river is reconstituted near the mouth by drainage from the Wellton-Mohawk Irrigation Project area. The effects of this drainage on mineral quality of the Lower Colorado River were included in the Project studies.

The waters in the upper portion of the Little Colorado River Subbasin are impounded and consumptively used to the extent that flow below Winslow, Arizona, becomes intermittent. Continuous flow is reestablished near the river's mouth by discharges from Blue Springs. Both the intermittent flow from the lower river reaches and the flow from the springs were included in the studies of the Lower Colorado River, but it was not possible to quantify the effects of irrigation in the headwaters area of the Little Colorado River.

In this Appendix, the term "Lower Colorado River Basin" is used to describe the drainage area which actually contributes significant flow to the Lower Colorado River. This excludes the reaches of the Little Colorado and Gila Rivers above the points at which the streams are discontinuous or intermittent.

FIELD STUDY METHODS

Collection of Basic Information

Basic information on irrigated acreage; cropping patterns; locations of springs and seeps; location, volume and quality of industrial waste discharges; quantity and quality of oil field brine and brackish water production; the effect of mine drainage; and other factors on mineral quality of Colorado River Basin streams was collected during the course of the field investigations. This information was obtained through interviews with responsible officials of irrigation districts, farm operators, county agents, State Engineers and staff, and faculty of agricultural schools, by detailed map and ground reconnaissance of streams and tributary areas, and by review and updating of municipal and industrial waste inventories. Project personnel made full utilization of the excellent information on geology, geohydrology, and stratigraphy of the Upper Colorado River Basin contained in the U. S. Geological Survey Report by Iorns and his associates.(4) Since no such compendium on Lower Colorado River Basin conditions was available, it was necessary for Project personnel to develop the water-related geological information for this area.

Water Quality Investigations

As indicated in Chapter III, various agencies, most notably the U. S. Geological Survey, have obtained mineral quality data at sampling stations throughout the Colorado River Basin. These sampling locations generally were selected to evaluate the effects of specific geohydrological factors or individual water resources projects. Data from these stations were of great value to the Project, but the stations did not provide sufficient areal coverage to meet Project objectives. Accordingly, the Project carried out a two-phase water quality-quantity study with the following principal features and objectives:

1. A network of sampling stations at key locations on principal streams within the Colorado River Basin. These stations, hereafter referred to as "main network stations" were located, insofar as possible, to provide measurement of salt loads entering and leaving significant watersheds, to define the magnitude of changes in mineral composition within critical reaches of streams, and to provide data for input to the Project's routing model studies. The locations of these stations in the Upper and Lower Colorado River Basins are shown on Figures 14 and 15, respectively.
2. Measurement of flow and mineral quality of selected streams, irrigation diversions and returns, and point sources of salinity. The stations sampled in connection with this activity are referred to, in this Appendix, as "survey stations." The Upper Colorado River Basin was subdivided into 29 watersheds or "study areas" for which salt and water budgets were developed. The locations of the 29 study areas are shown in Figure 16. Relative salt yields from these areas were evaluated in terms of the total salt load entering Lake Powell. The Lower Colorado River Basin studies were carried out in much the same manner. Budgets were developed for the reach between Lees Ferry and

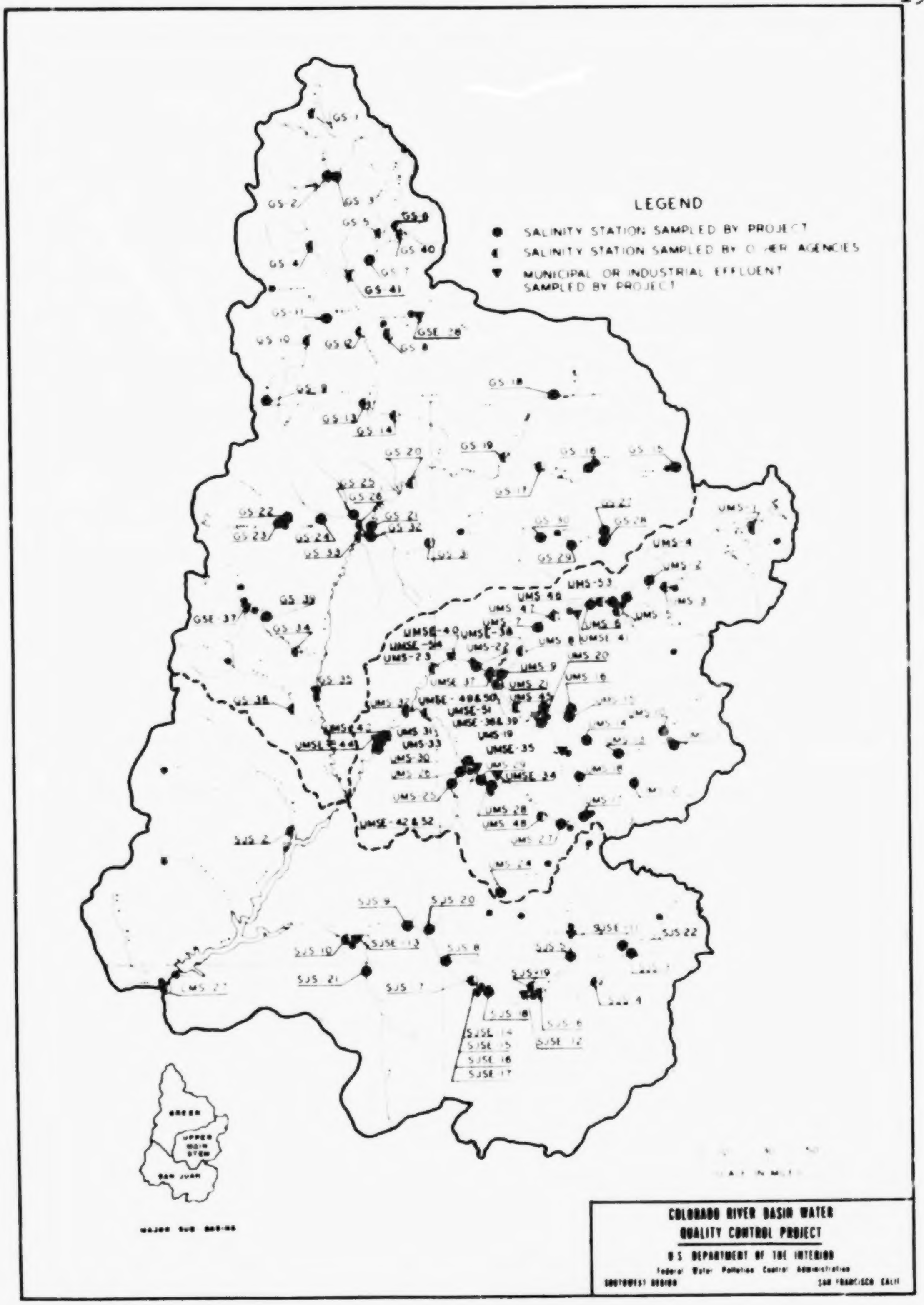

LEGEND
SALINITY STATION SAMPLED BY PROJECT
SALINITY STATION SAMPLED BY OTHER AGENCIES
MUNICIPAL OR INDUSTRIAL EFFLUENT SAMPLED BY PROJECT
GREEN
UPPER MAIN STEM
SAN JUAN
MAJOR SUB BASINS
COLORADO RIVER BASIN WATER
QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO CALIF

Figure 14 Main Network Sampling Stations Upper Colorado River Basin

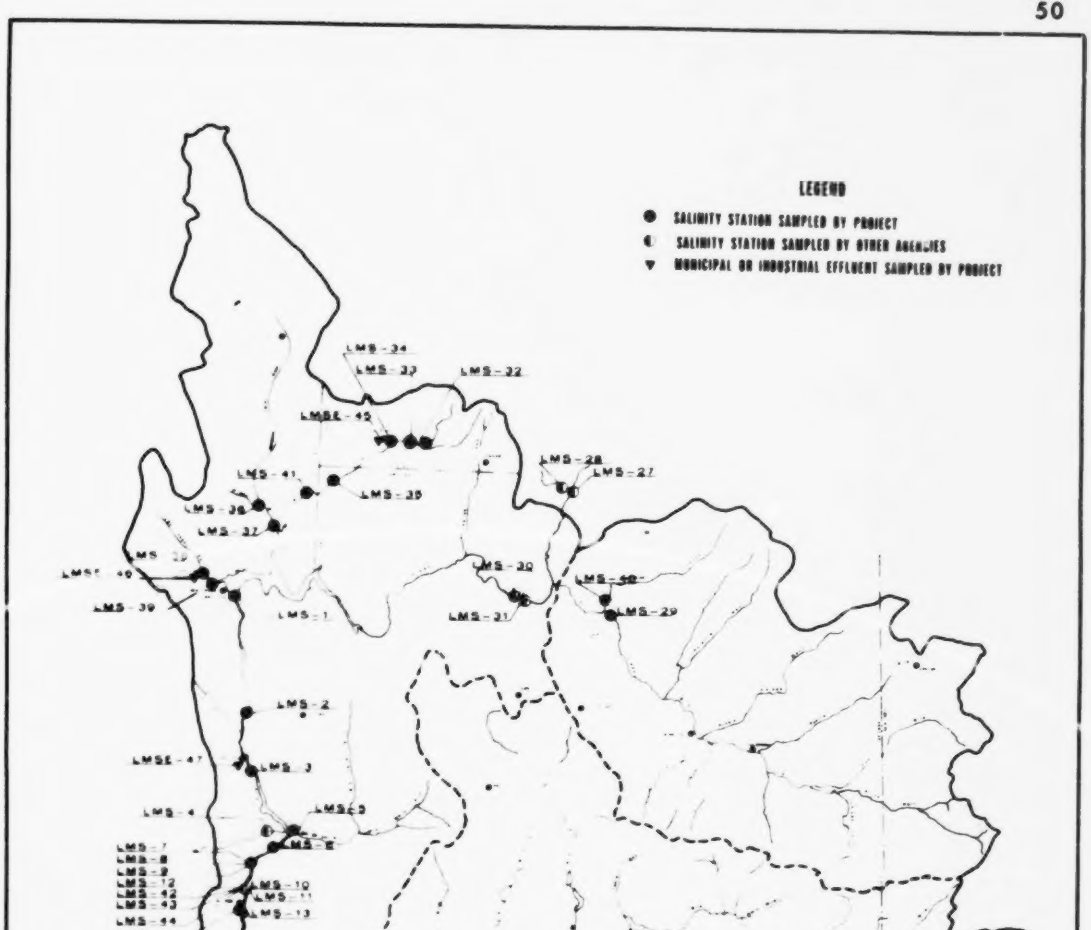
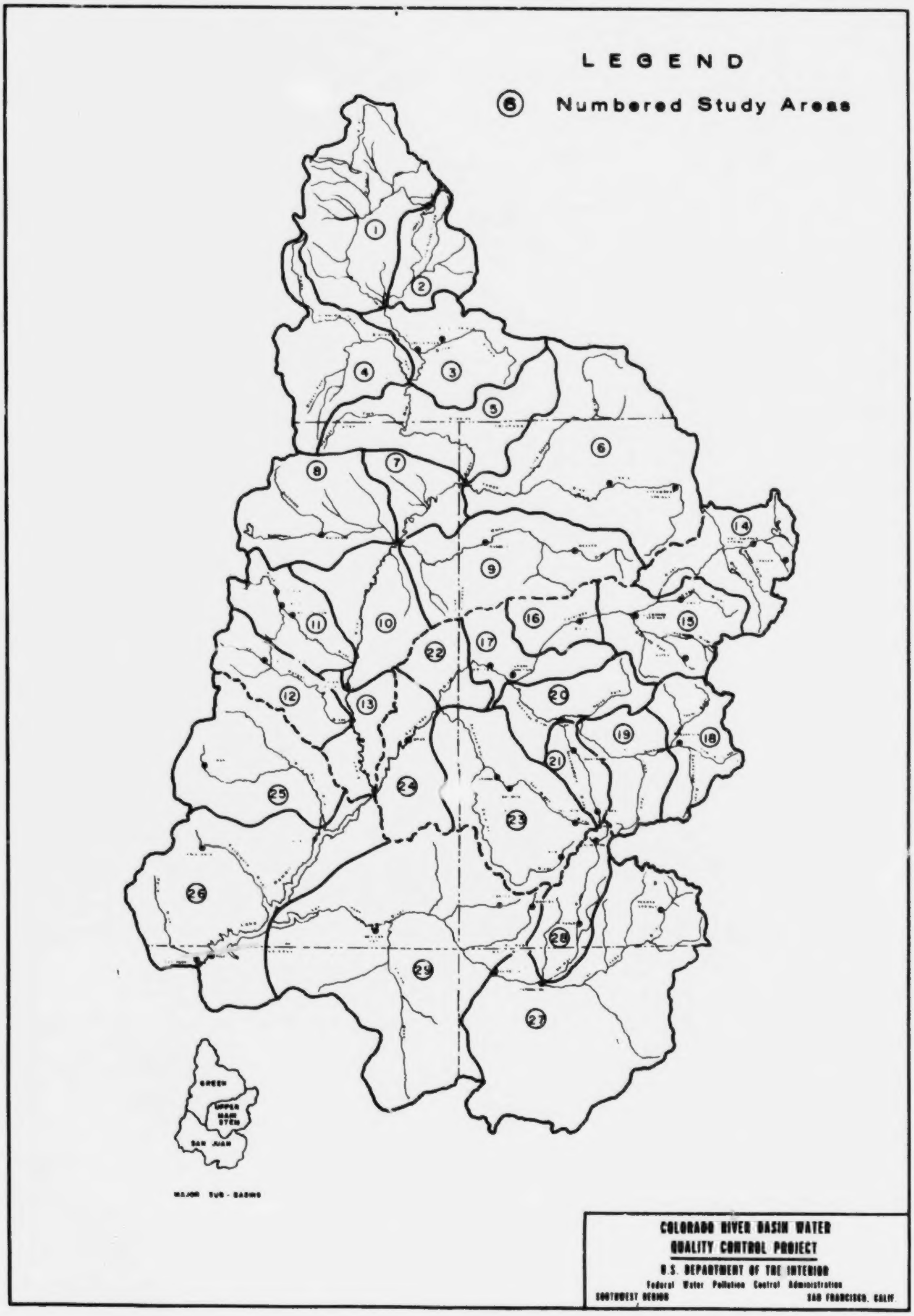

LEGEND
● SALINITY STATION SAMPLED BY PROJECT
◐ SALINITY STATION SAMPLED BY OTHER AGENCIES
▼ MUNICIPAL OR INDUSTRIAL EFFLUENT SAMPLED BY PROJECT
LMS-34
LMS-33
LMS-32
LMSE-45
LMS-41
LMS-35
LMS-28
LMS-27
LMS-36
LMS-37
LMS-38
LMSE-49
LMS-39
LMS-1
LMS-30
LMS-31
LMS-40
LMS-29
LMS-2
LMSE-47
LMS-3
LMS-4
LMS-5
LMS-7
LMS-8
LMS-9
LMS-6
LMS-12
LMS-42
LMS-43
LMS-44
LMS-14
LMS-10
LMS-11
LMS-13
LMS-15
LMS-19
LMSE-48
LMS-16
LMS-20
LMS-24
LMS-26
MAJOR SUB BASINS
COLORADO RIVER BASIN WATER
QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

Figure 15 Main Network Sampling Stations Lower Colorado River Basin


LEGEND
6 Numbered Study Areas
1
2
3
4
5
6
7
8
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11
12
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14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
GREEN
UPPER MAIN STEM
SAN JUAN
MAJOR SUB-BASINS
COLORADO RIVER BASIN WATER
QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF.

Figure 16 Study Areas, Upper Colorado River Basin

Hoover Dam, and for the reach between Hoover Dam and the Northerly International Boundary. It was not possible to develop a budget for the reach between the Northerly and Southerly International Boundaries, known as the "Limitrophe Section."

Where possible, water quality stations maintained by the U. S. Geological Survey, the Bureau of Reclamation, and other State and Federal agencies were incorporated in the Project's field studies. Project sampling stations were located near existing USGS flow-measurement stations where possible. In situations where flow data were not available, Project personnel performed the necessary stream gaging and stage measurements.

Main network stations were sampled at two-week intervals. Samples were subjected to measurement of physical parameters in the field, and to complete1/ mineral analysis at the Project laboratory in Salt Lake City, Utah.

Survey stations were sampled at monthly intervals and samples for alternate months were subjected to complete analysis. Specific conductance was measured on samples collected for intervening months. TDS-conductivity relationships developed at the survey stations were utilized to estimate TDS concentrations for the samples for which only conductivity was measured.

The study methods employed did permit differentiation between the salt concentrating and salt loading effects discussed in Chapter III of this Appendix. Although the distinction between the two effects is clear in the case of springs, some municipal and industrial effluents, and

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1/ Calcium, Magnesium, Sodium plus Potassium, Chloride, Sulfate, Bicarbonate, residue at 180°C, pH, and Specific Conductance.

discharges of water used only for cooling, most of the results of this study represent the combined salt loading and salt concentrating effects.

Raw analytical data developed in the course of the field studies are too voluminous for inclusion in this Appendix. These data have been furnished to the Conferees, and to participating and cooperating agencies at periodic intervals. Printouts of the raw data are available for examination at the Project Office in Denver, Colorado.

Evaluation of Discrete Sources of Dissolved Minerals. Springs and seeps, for which salt loads were available in various reports and publications, were checked by field measurements. Salt yields were measured and documented for other springs which were located by field reconnaissance. Several abandoned oil-test wells were found to be discharging significant salt loads to Basin streams. An open file report, providing salient information on all known discrete natural sources of mineralized water in the Basin, has been prepared and is available in the Project Office.(14)

The salt loads contributed by municipal effluents were measured at thirteen representative communities within the Basin. The quantity and mineral quality of domestic water supplies, and of waste water discharged to surface streams, were determined. Based upon data obtained at the thirteen representative communities, salinity contribution coefficients (tons of salt per day per 1000 population) were developed and used in calculating salt loads for other communities throughout the Basin.

Salt contributions from industries having direct discharge of industrial wastes, process water, or cooling water to streams were documented by flow measurement and sampling at appropriate intervals. Salt loads contributed by discrete return flows in surface drains from irrigated areas were evaluated in the same manner.

The major producing oil fields within the Basin were surveyed on a well-by-well basis to determine the extent and magnitude of the salt loads attributable to disposal of produced water and other oil-field activities.

Coal and metals mining operations, and associated mills and refineries, were examined to ascertain their contribution of both mineral salts and heavy metals to Basin streams.

Evaluation of Diffuse Sources of Dissolved Minerals. Mineral quality data developed from sampling of network and survey stations were used to prepare water and salt budgets for the study areas. These budgets were then utilized to calculate the flow and total dissolved solids yields of unit areas. The technique used has been described by Iorns and his associates.(4) The Project studies, however, utilized quality and flow data for specific days, and included data for every known significant inflow within each area. Iorns' work was based upon mean values for fewer sampling stations.

The water and salt budgets were based upon data from all gaged and measured runoff[1/] to the stream system, runoff from ungaged tributaries, and measured outflows. The flow and salt loads for ungaged tributaries were derived by correlation with nearby gaged streams with appropriate adjustments for variation in geological characteristics and precipitation.

[1/] As used in this Appendix, the term "runoff" refers to all of the water flowing in the stream channel and includes surface runoff, interflow, and base flow. "Surface runoff" includes only the water that reaches the stream channel without percolating to the water table.(15)

The difference between the calculated input loads and flows and the measured outflow, from the areas studied, was attributed to leaching and seepage associated with irrigation, and direct overland runoff to streams. The magnitude of the direct overland runoff from most areas was insignificant except during periods of snowmelt. Field observations, streamflow records, and U. S. Weather Bureau records were used to obtain estimates of the periods and magnitude of overland runoff. Periods of irrigation diversions occurred only during summer and early fall months, and were thus easily distinguished from periods of snowmelt. Return seepage from irrigation which carried leached salts continued throughout the year in most areas.

For irrigated areas served by surface water supplies, water and salt budgets were structured so that only salt added to the streams by leaching was attributed to irrigation. Where areas were irrigated with ground-water, the entire salt load was attributed to irrigation since the dissolved minerals in the pumped ground-water in most cases would not have reached the immediate reach of stream in the absence of pumping for irrigation.

The water and salt budget method utilized in these studies is well suited to headwaters areas, where streamflow and quality are sensitive to small inputs of water and salt. The method is less suitable for downstream reaches where errors in flow measurement or laboratory analyses can mask or distort the calculated response to salt inputs. Owing to the very large diversions and the highly developed systems of irrigation drains, the Lower Colorado River Basin studies were treated in terms of the effect of each salt load input and diversion on the stream.

Outcrop patterns for the various geologic formations in the Upper Colorado River Basin are shown on U. S. Geological Survey bedrock geology maps for the Basin States. The geohydrologic characteristics of the pertinent formations are summarized on Plate No. 1 of USGS Professional Paper No. 441.(4)

Evaluation of Changes in Mineral Composition. Changes in the relative proportions of chemical constituents in water may occur with, or without, changes in the total dissolved solids content. Such changes may result from ion exchange, precipitation or solution of mineral compounds, or the addition of water having a different chemical composition. Composition changes between key sampling stations, and the relationship of composition of major inflows to that of receiving streams, were studied by the method outlined by Hem in USGS Water Supply Paper No. 1473.(5)

RESULTS OF FIELD INVESTIGATIONS - UPPER BASIN

A brief description of each of the study areas in the Upper Colorado River Basin and the significant findings of the field studies for each are presented in the following sections. Detailed discussions of each study area are contained in an open file report(16) which is available for inspection at the Project Office in Denver, Colorado.

Study Area 1 (Green River Subbasin)

Description. Area 1 consists of the Green River drainage upstream of Big Sandy Creek, which encompasses 4,922 square miles in Sublette, Lincoln, and Sweetwater Counties in Wyoming (Figure 17). Elevations range from 6,300 feet at the junction of the Green River and Big Sandy Creek to 13,785 feet on Gannett Peak in the Wind River Range.

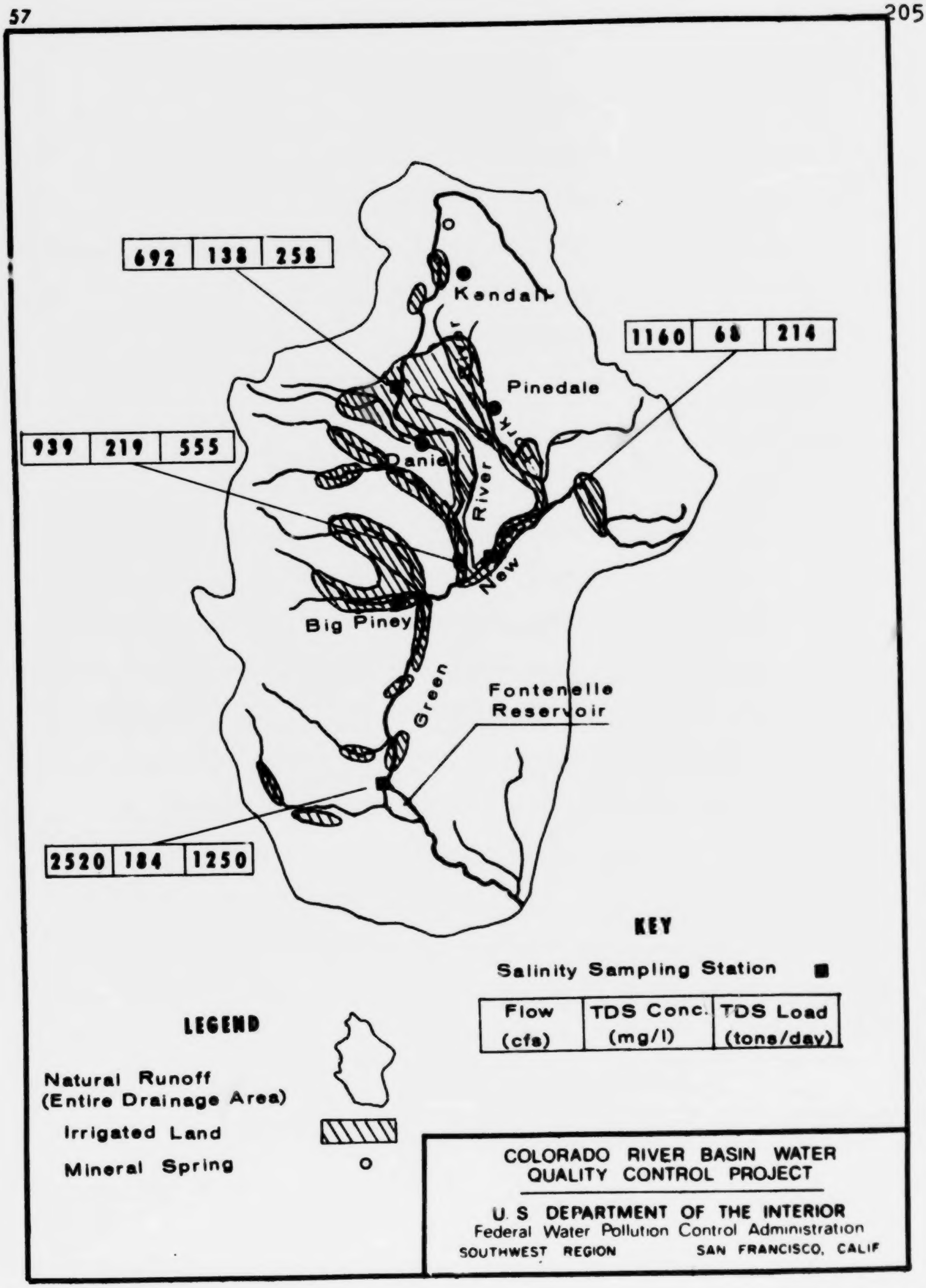
692 | 138 | 258
Kendall
1160 | 68 | 214
Pinedale
939 | 219 | 555
Daniel
River
New
Fork
Big Piney
Green
Fontenelle
Reservoir
2520 | 184 | 1250
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Mineral Spring ○
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

Figure 17 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 1, Upper Colorado River Basin, 1965–66

The higher portions of the Wind River Range are composed of highly resistant igneous and metamorphic rocks. Precipitation on these uplands ranges from 20 to 50 inches per year. Because of the abundant precipitation and resistant characteristics of these areas, streams draining from them yield large flows of good quality water. The northern end of the Wind River Range and the entire Wyoming Range contain more soluble sedimentary rocks that were deposited during the Cretaceous age. Although there is less precipitation on these mountain ranges, the soluble rocks yield runoff having TDS concentrations of 200 to 1,000 mg/l. Most of Area 1 is underlain by Tertiary rocks which were deposited in a brackish lake. The old residual lake beds contain highly saline materials and yield base flow to streams having TDS concentrations of from 300 to 7,000 mg/l.

Findings. Most of the flow in streams of Area 1 originates in the higher mountain areas and is of excellent quality. Nearly all of the salt load contributed by the area is derived from the saline lake bed materials in the central portion of the area.

Two mineral springs near Kendall added 26 tons of salt per day. Irrigation of about 81,000 acres of hay and pasture land added approximately 30 tons of salt per day (Figure 17). The average salt contribution from irrigation was 0.1 ton per acre per year.

Ionic composition diagrams for streams of this area have the triangular shape which is characteristic of most headwaters streams in the Upper Colorado River Basin. A general increase in total dissolved solids concentration occurs between Warren Bridge and the mouth of the New Fork

River. Inflow from the New Fork River improved quality in the Green River downstream of the confluence of the two streams, but there were no important changes in the relative proportions of chemical constituents in streams of Area 1 (Figure 48).

The salt budget for Area 1 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Springs	26	2.1
Irrigation	30	2.4
Runoff	1194	95.5
Sub-Total	1250	
Decrease in Storage	160	
Net	1410	

Study Area 2 (Green River Subbasin)

Description. Area 2 covers approximately 1,720 square miles in Sublette, Fremont, and Sweetwater Counties in Wyoming, and includes the entire drainage area of Big Sandy Creek (Figure 18).

The topography of the area ranges from extreme relief in the Wind River Mountain Range, to relatively flat desert land along Big Sandy Creek. Elevations range from 6,300 feet at the confluence of the Green River and Big Sandy Creek, to more than 12,000 feet in the Wind River Mountains.

The headwaters areas of Big Sandy Creek and its tributaries are underlain by insoluble pre-Cambrian rocks of the Wind River Range. These peaks, which constitute a minor portion of the area, yield most of the runoff in Area 2. A minor portion of the runoff is derived from Green River Desert areas which are underlain by saline Tertiary lake bed materials. Effluent ground-water from the saline lake beds reaches Big Sandy Creek near its mouth.

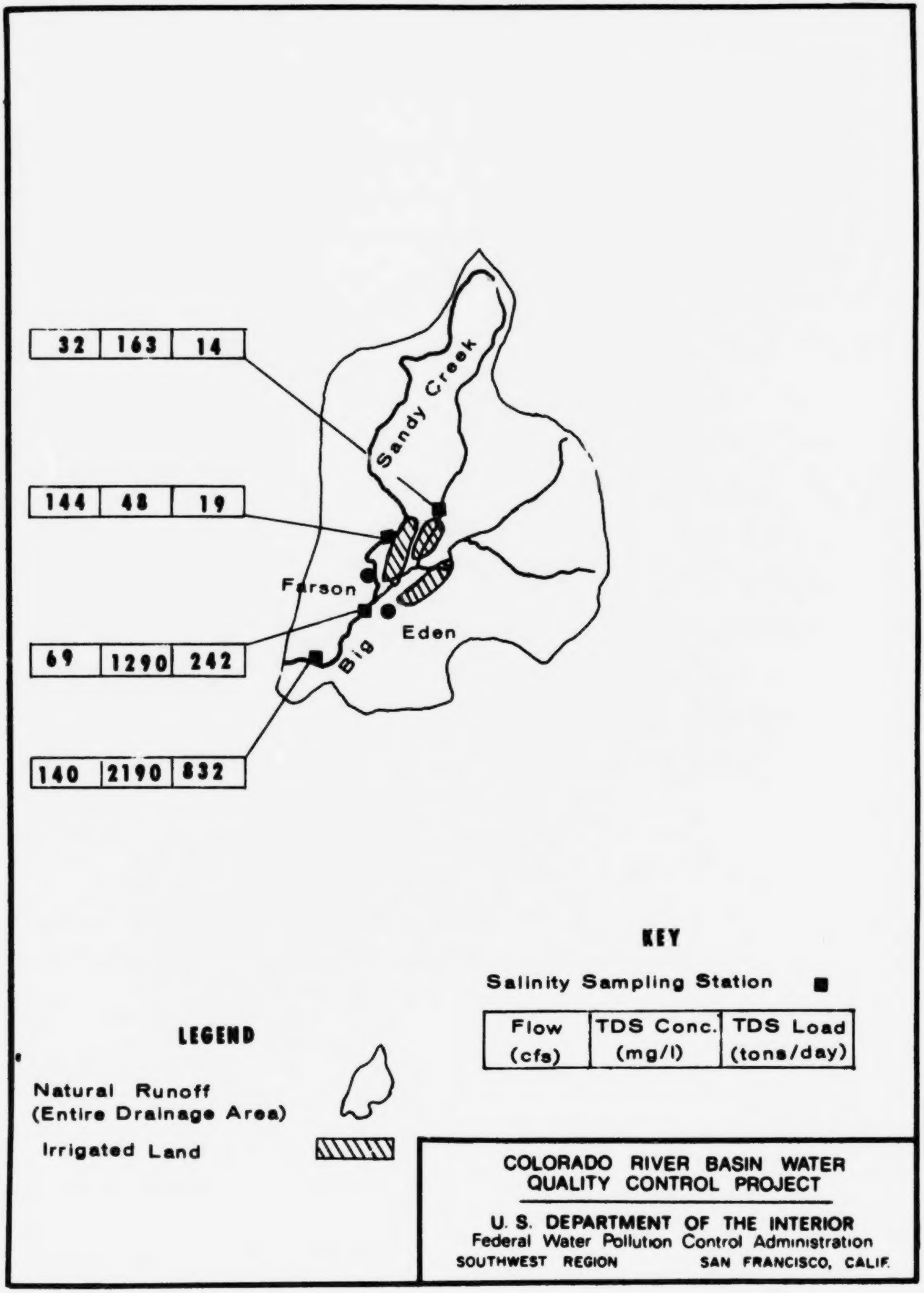
32 | 163 | 14
144 | 48 | 19
69 | 1290 | 242
140 | 2190 | 832
Sandy Creek
Farson
Eden
Big
KEY
Salinity Sampling Station ■
Flow (cfs) | TDS Conc. (mg/l) | TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
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Figure 18 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 2, Upper Colorado River Basin, 1965–66

Findings. During the study period, the headwaters streams located in insoluble outcrop areas yielded approximately 10 tons of salt per day. The irrigation of 13,000 acres contributed approximately 200 tons of salt per day, or an average of 5.6 tons per acre per year. The salt load yield from these irrigated areas was among the highest observed within the Basin, and results from leaching of the soluble gypsiferous sediments. Groundwater seepage from saline lake beds caused an increase in flow of 71 cfs and a salt load increase of 590 tons per day between the USGS gage below Eden, Wyoming, and the mouth of Big Sandy Creek.

The chemical composition changed from essentially pure water in the headwaters areas to predominantly sulfate-type water at the sampling station below Eden, Wyoming. All cations increased above the Eden station, and sodium became predominant in the reach below Eden. Chemical composition of Big Sandy Creek, at its mouth, was essentially identical to that of seepage collected in the stream reach below Eden. The high sulfate content of the seepage water is caused by solution of gypsum underlying the area.

The salt budget for Area 2 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Irrigation	200	24
Runoff	632	76
Total	832	

Study Area 3 (Green River Subbasin)

Description. Area 3 comprises the Green River drainage area between Big Sandy Creek and Blacks Fork River, which covers approximately 2,960 square miles in Sweetwater County in Wyoming (Figure 19). Rock Springs

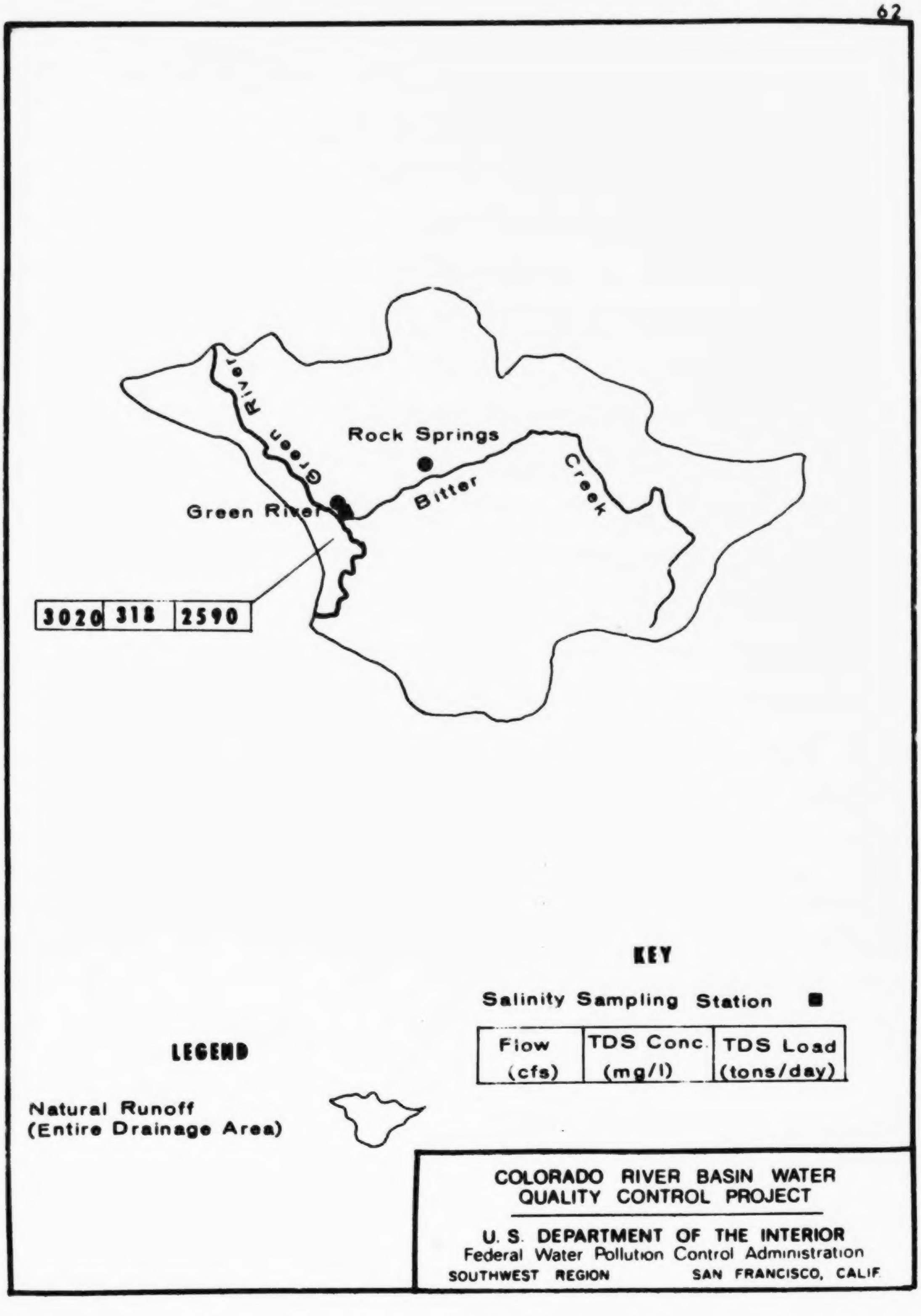
Green River
Rock Springs
Bitter Creek
Green River
3020
318
2590
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
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Figure 19 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 3, Upper Colorado River Basin, 1965–66

and Green River, with 1960 populations of 10,371 and 3,496, respectively, are the only significant communities in the area. Bitter Creek is the only significant tributary to the Green River within Area 3. The Bitter Creek drainage area is underlain by continental and marine rocks which are mostly shale and shaley sandstone of Cretaceous and Tertiary age. The Bitter Creek area receives very little precipitation and yields only small quantities of water except during periods of storms.

Findings. The increase of 360 cfs and 481 tons of salt per day from the tributary area between Fontenelle Dam and the mouth of Bitter Creek resulted from seepage of mineralized ground-water from highly saline rocks underlying the drainage area.

The flow and salt load contribution by Bitter Creek varied widely during the year. Flows ranged from 4 to 40 cfs and the salt load varied from 26 to 280 tons per day. Flow data were insufficient to permit calculation of a mean annual salt load contribution. It is estimated, based upon available data, that natural runoff from the highly saline geologic formations in the Bitter Creek watershed added a salt load of more than 30 tons per day to the area. Discharges from the communities of Rock Springs and Green River added a salt load of one ton per day.

The chemical composition diagram for the station near Green River, Wyoming, showed a significant increase in sulfate due to the saline inflow within the reach (Figure 48).

The salt budget for Area 3 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Municipal	1	0.3
Irrigation	30	8.6
Runoff	317	91.1
Total	348	

Study Area 4 (Green River Subbasin)

Description. Area 4 includes the entire Blacks Fork River drainage basin which covers 3,630 square miles in Lincoln, Uinta, and Sweetwater Counties in Wyoming; and Summit County in Utah (Figure 20). Kemmerer and Lyman, the only sizeable communities within the area, had populations of 2,028 and 425, respectively, in 1960.

Elevations of the area range from 6,000 to more than 10,000 feet. Annual precipitation isohyets roughly parallel the contours and range from less than 8 inches to more than 40 inches per year.

Principal tributaries to Blacks Fork River are Muddy Creek and Hams Fork River. Blacks Fork River heads high in the rugged, glaciated Uinta Mountains. Muddy Creek and Hams Fork River head in the Wyoming Mountains. Virtually all runoff in the area is derived from the Uinta Mountans which are underlain by insoluble igneous and metamorphic rock which yield water of excellent quality. Only a minor portion of the flow originates in the higher glacial moraine areas just north of the Utah-Wyoming line.

Findings. "Reagan Spring," located near Interstate 80 bridge over Muddy Creek contributed approximately 2 tons of salt per day.

Irrigation of 71,000 acres in the vicinity of Lyman, Mountainview, and Fort Bridger, contributed a salt load of 475 tons per day or an average of 2.4 tons per acre per year. This yield is significantly larger than the 0.9 tons of salt per acre per year reported by Iorns, et al. This disparity probably reflects leaching of new lands brought under irrigation since preparation of the Iorns report. Irrigation of 7,000 acres of hay and pasture lands upstream of Frontier, Wyoming, added a salt load of 6 tons per day to the system.

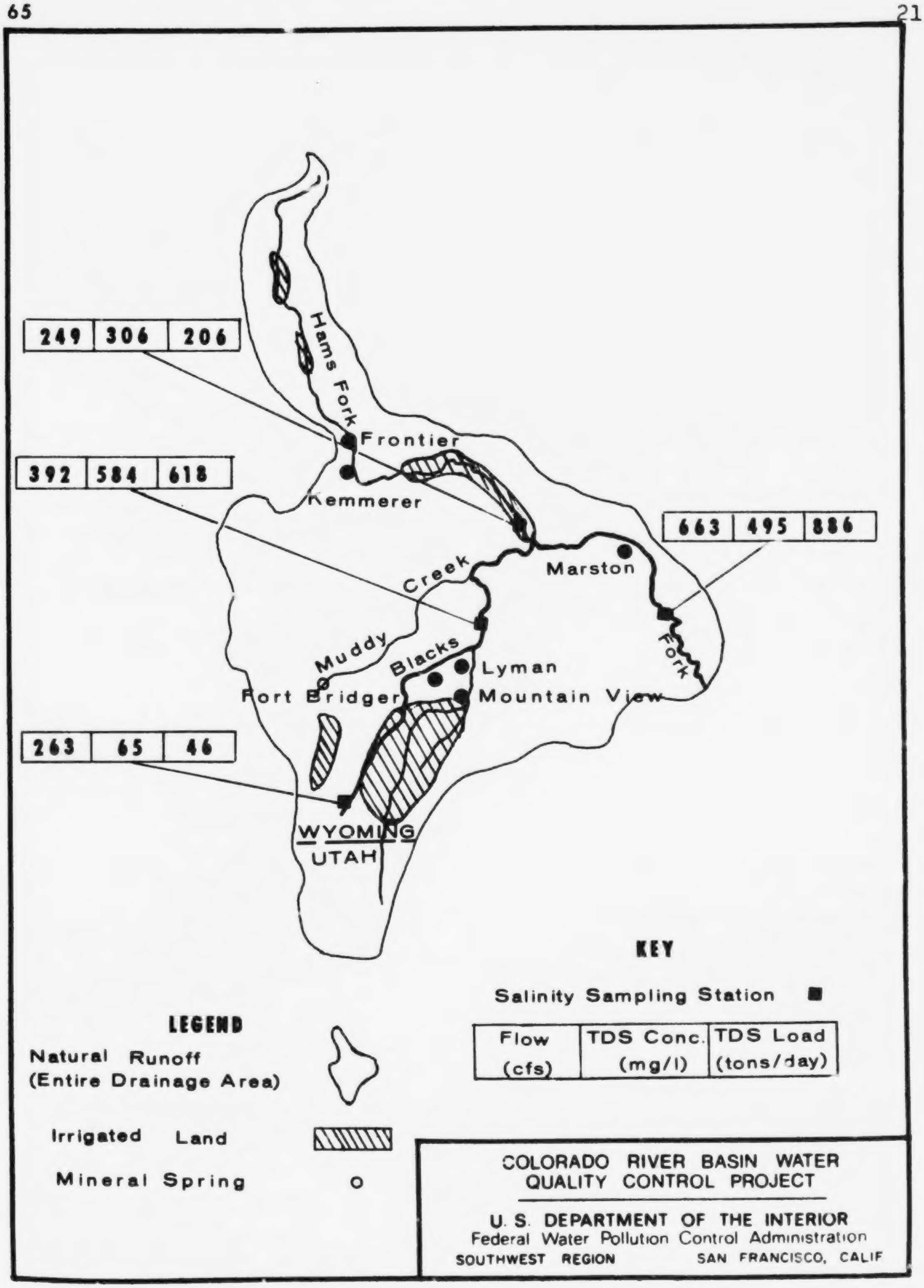
249 | 306 | 206
392 | 584 | 618
663 | 495 | 886
263 | 65 | 46
Hams Fork
Frontier
Kemmerer
Marston
Fork
Muddy Creek
Blacks
Lyman
Mountain View
Fort Bridger
WYOMING
UTAH
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Mineral Spring ○
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Figure 20 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 4, Upper Colorado River Basin, 1965–66

The salt budget for Area 4 is presented in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Irrigation	481	54.3
Springs	2	0.2
Runoff	403	45.5
Total	886	

Study Area 5 (Green River Subbasin)

Description. Area 5 includes the Green River drainage between the mouth of Blacks Fork River and the mouth of the Yampa River (Figure 21). It covers 3,555 square miles in Sweetwater County in Wyoming; Summit and Daggett Counties in Utah; and Moffat County in Colorado.

The headwaters of the area are located on the older sediments and igneous outcrops of the Uinta Mountains. This small area yields virtually all runoff within the study area. In Utah, the Green River crosses a small outcrop of sediments of Cretaceous through Mississippian age which yield good quality water. Downstream from Sheep Creek, the Green River crosses a fault and enters the canyon cut in pre-Cambrian meta-sediments of the Uinta Range which also yield high quality water. The sediments to the north and east of the Green River yield smaller amounts of water with higher concentrations of dissolved minerals.

Findings. The Uinta Mountains yield most of the runoff within Area 5. Runoff from these headwaters areas is of excellent quality. Small amounts of tributary inflow in the downstream areas contain variable amounts of minerals dissolved from the sedimentary formations. Irrigation of 18,000 acres of hay and pasture lands along Henrys Fork contributed a salt load of 243 tons per day or an average of 4.9 tons per acre

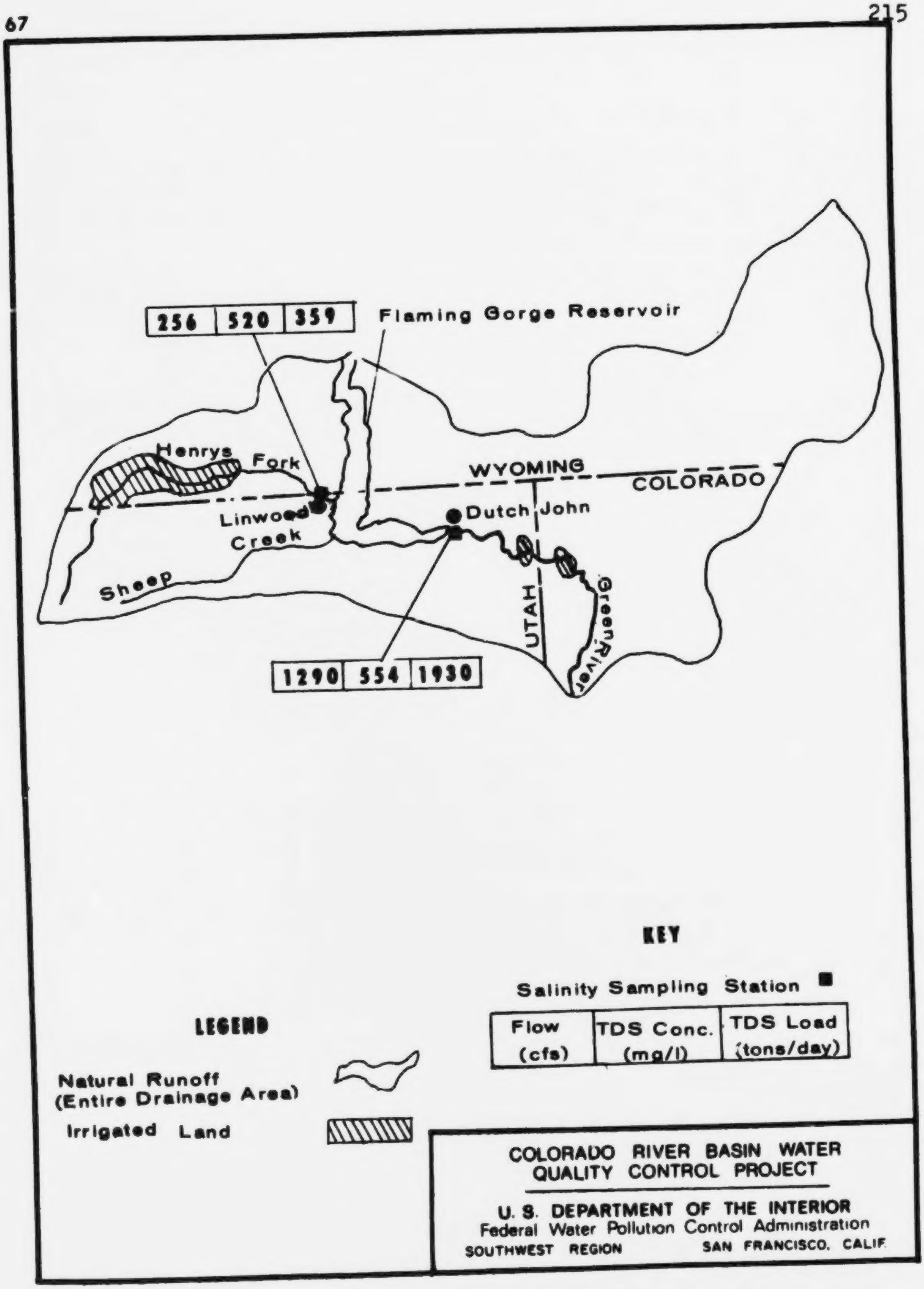
256
520
359
Flaming Gorge Reservoir
Henrys Fork
Linwood Creek
Sheep
WYOMING
COLORADO
Dutch John
UTAH
Green River
1290
554
1930
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
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Figure 21 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 5, Upper Colorado River Basin, 1965–66

per year. This relatively large salt contribution is due to the leaching of the soluble sediments which underly most of the irrigated area.

Runoff added more than 2,300 tons per day to the total salt load from the area. Most of this load originates from the soluble sediments of the lower areas. During the study period, storage in Flaming Gorge Reservoir caused a negative salt load balance for Area 5.

Chemical composition of Henrys Fork at Linwood is predominated by calcium sulfate and with the exception of a low sodium content, is typical of Upper Basin streams which receive drainage from irrigated areas (Figure 48). Mineral composition of the Green River below inflows from Blacks Fork and Henrys Fork is typical of mature streams in the Basin, i.e., calcium and sodium are the predominant cations, and sulfate concentrations exceed those of bicarbonate and chloride.

The salt budget for Area 5 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Irrigation	243	9.4
Runoff	2337	90.6
Flaming Gorge Reservoir Storage	-3770	
Total	-1190	

Study Area 6 (Green River Subbasin)

Description. Area 6 includes the entire Yampa River drainage basin, and covers 3,560 square miles in Routt and Moffat Counties in Colorado; and Carbon and Sweetwater Counties in Wyoming (Figure 22). Principal communities within the area included Steamboat Springs, Hayden, Craig, and Maybell in Colorado; and Baggs in Wyoming.

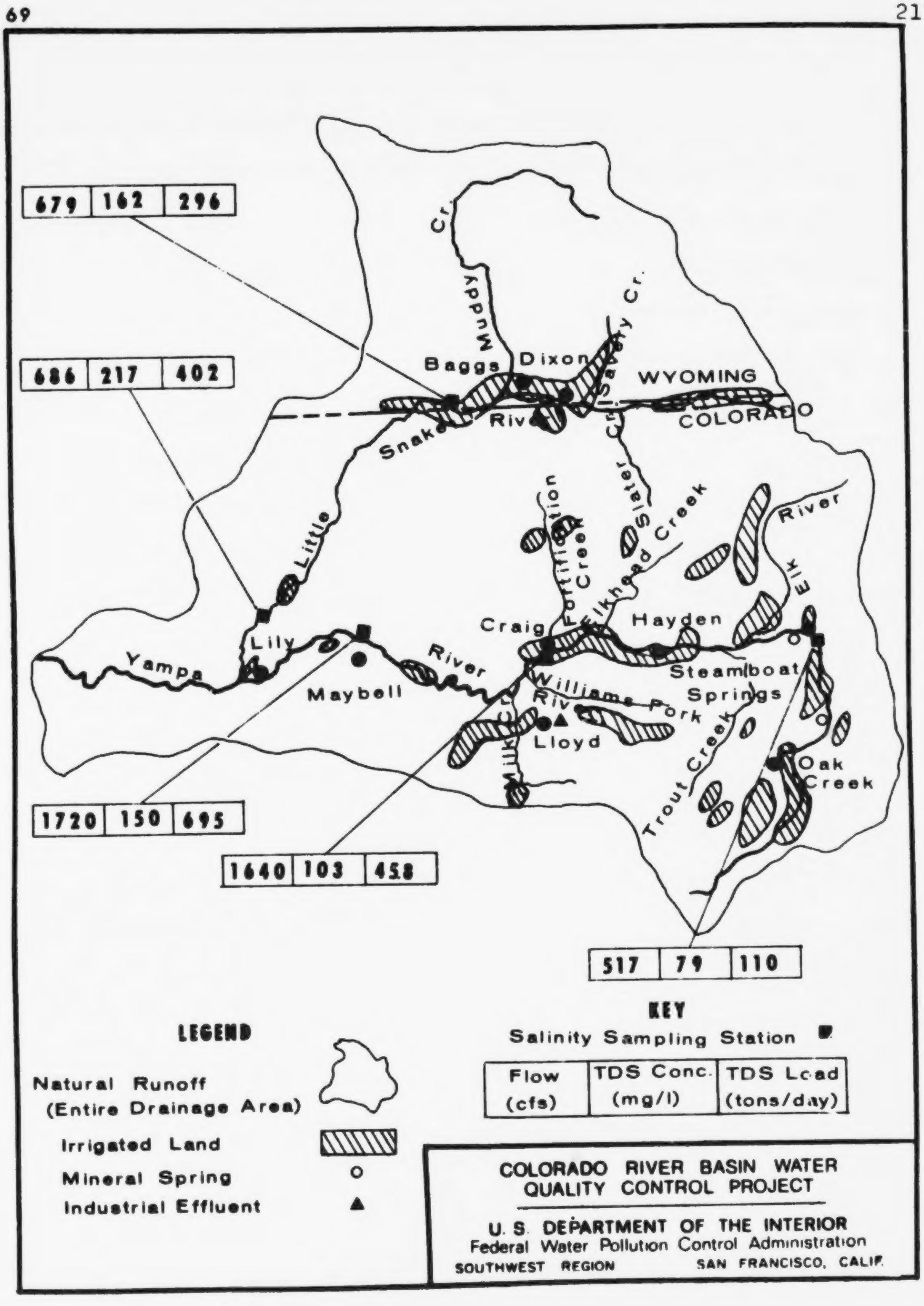
679 | 162 | 296
686 | 217 | 402
1720 | 150 | 695
1640 | 103 | 458
517 | 79 | 110
Muddy Cr.
Savery Cr.
Baggs
Dixon
WYOMING
COLORADO
Snake River
Slater Cr.
Fortification Creek
Elkhead Creek
Little Snake
Elk River
Craig
Hayden
Lily
Yampa River
Maybell
Williams Fork River
Milk Cr.
Lloyd
Steamboat Springs
Trout Creek
Oak Creek
KEY
Salinity Sampling Station
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
Mineral Spring
Industrial Effluent
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Figure 22 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 6, Upper Colorado River Basin, 1965–66

The Yampa River heads on flat-lying lava flows of the White River Plateau at elevations greater than 12,000 feet. Major tributaries upstream of Steamboat Springs head in mountains of the Park Range along the Continental Divide. These headwater areas are underlain by insoluble granitic rocks. Precipitation on these high areas exceeds 50 inches per year and runoff is of excellent quality. Downstream areas receive as little as 10 inches of precipitation per year. Runoff from these saline formations contains moderate concentrations of dissolved minerals.

Findings. The TDS concentrations in Yampa River near Oak Creek, Colorado, ranged from 177 mg/l to 329 mg/l during the study period. The concentrations in the Yampa River at Steamboat Springs ranged from 29 to 174 mg/l. This illustrates the effect of the high quality runoff from the Park Range which enters the Yampa above Steamboat Springs.

The total salt load of 110 tons per day in the Yampa River at Steamboat Springs includes approximately 6 tons per day from an abandoned coal mine located along Oak Creek just downstream of Oak Creek, Colorado. Mineral springs in the vicinity of Steamboat Springs add approximately 24 tons of salt per day. Irrigation of approximately 38,000 acres of forage land contributes 20 tons of salt per day or an average of 0.2 ton per acre per year.

The mean flow and salt load in the Yampa River at Craig, Colorado, was 1,643 cfs and 458 tons per day, respectively. This reflects an addition of 1,126 cfs and 324 tons of salt per day downstream of Steamboat Springs. Approximately 300 tons per day of this load is from natural runoff contributed by Elk River, Elkhead Creek, Trout Creek, Fortification

Creek, and other small streams. The remaining salt load addition of 24 tons per day results from irrigation along the Yampa River and its tributaries. The average salt yield from irrigation was approximately 0.4 tons per acre per year. This value is in close agreement with the findings of Iorns, et al.(4)

The Yampa River at Maybell carried a mean annual flow of 1,720 cfs and a mean salt load of 695 tons per day during the study period. This represents an increase of 78 cfs and 237 tons per day over the flow and salt load of the Yampa River at Craig. The release of saline water from the Iles Dome Oil Field located south of Lloyd, Colorado, was responsible for the addition of 4 cfs and 17 tons of salt per day. Inflow from Milk Creek added 96 tons of salt per.day and 30 cfs. Approximately 6 tons per day of this addition resulted from irrigation of 2,100 acres of forage area along Milk Creek. Natural runoff from Mancos shale outcrop areas contributed 90 tons of salt per day. The Williams Fork River yielded a salt load of 64 tons per day and a flow of 44 cfs. A Portion of this load resulted from spillage of brine produced in the Williams Fork Oil Field. Release of this saline water was discontinued during the study period. Irrigation of 16,000 acres along Williams Fork added an estimated 13 tons of salt per day to the system.

Observed changes in chemical composition of the Yampa River between Steamboat Springs and Maybell were insignificant (Figure 48). Although TDS concentrations decreased between Oak Creek and Steamboat Springs, the effect of the saline bedrock above Oak Creek is reflected by the increase in sodium concentration at Steamboat Springs.

The Little Snake River and Slater Fork one of its principle tributaries, yielded water with a TDS concentration of less than 160 mg/l throughout the year. This excellent quality water reflects the insoluble nature of the pre-Cambrian granite along the Continental Divide. Savery Creek, another tributary to the Little Snake River, discharged water with high salt concentrations derived from mineralized Tertiary sediments. Runoff per square mile from Savery Creek watershed was approximately equal to that for the Little Snake River; however, the salt contribution was about twice as great.

Approximately 15,000 acres of irrigated land above Dixon contributed 15 tons of salt per day or an average of 0.3 ton per acre per year to the Little Snake River. An additional 25 tons per day was added by irrigation of 17,000 acres along the Little Snake between Dixon and Baggs.

During the study period the Little Snake at Lily yielded a mean annual flow of 686 cfs and a salt load of 402 tons per day. The major portion of the salt load increase in Area 6 resulted from mineralized natural runoff and the solution of minerals from the bed and banks of the Little Snake River.

The salt budget for Area 6 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Springs	24	2.2
Irrigation	103	9.4
Industrial (Oil field produced water)[1/]	17	1.5
Mine Drainage	6	0.5
Runoff	950	86.4
Total	1100	

[1/] Does not include discharge of saline water from Williams Fork Oil Field which was discontinued during the study period.

Study Area 7 (Green River Subbasin)

Description. Area 7 includes the Green River watershed below the mouth of the Yampa River and above the mouth of the Duchesne and White Rivers. This 1,650 square mile area is located mostly within Uintah County of Utah but includes a small portion of Moffat County in Colorado (Figure 23). Major tributaries include Brush, Ashley, Cliff, and Jones Hole Creeks. Vernal, Utah, the only major community within the area, had a population of 3,655 in 1960.

Brush and Ashley Creeks originate high in the rugged, glaciated Uinta Mountains. The Jones Hole Creek drainage area consists of high uplands with deeply incised stream channels and steep hogbacks. The streams flow southward to the Uinta Basin, a plateau underlain by flat-lying sediments of Tertiary through Quaternary Ages. Elevations of the area range from less than 4,800 feet to more than 10,000 feet. Annual precipitation isohyets closely follow elevation contours and ranges from less than 8 inches per year on the lowlands to more than 40 inches per year on the Uinta peaks. Thus, most of the runoff in Area 7 is derived from a relatively small area of pre-Cambrian rock formation and is relatively free of dissolved minerals. The sediments of lower areas yield smaller quantities of salt-laden water.

Findings. Data from survey stations on Brush Creek and Little Brush Creek indicated that large losses of water occurred during the irrigation season, and smaller losses occurred during the base flow period. Salt loss occurred throughout the period of study indicating that salt may have been stored in some portions of the 5,100 acres of irrigated land within the area.

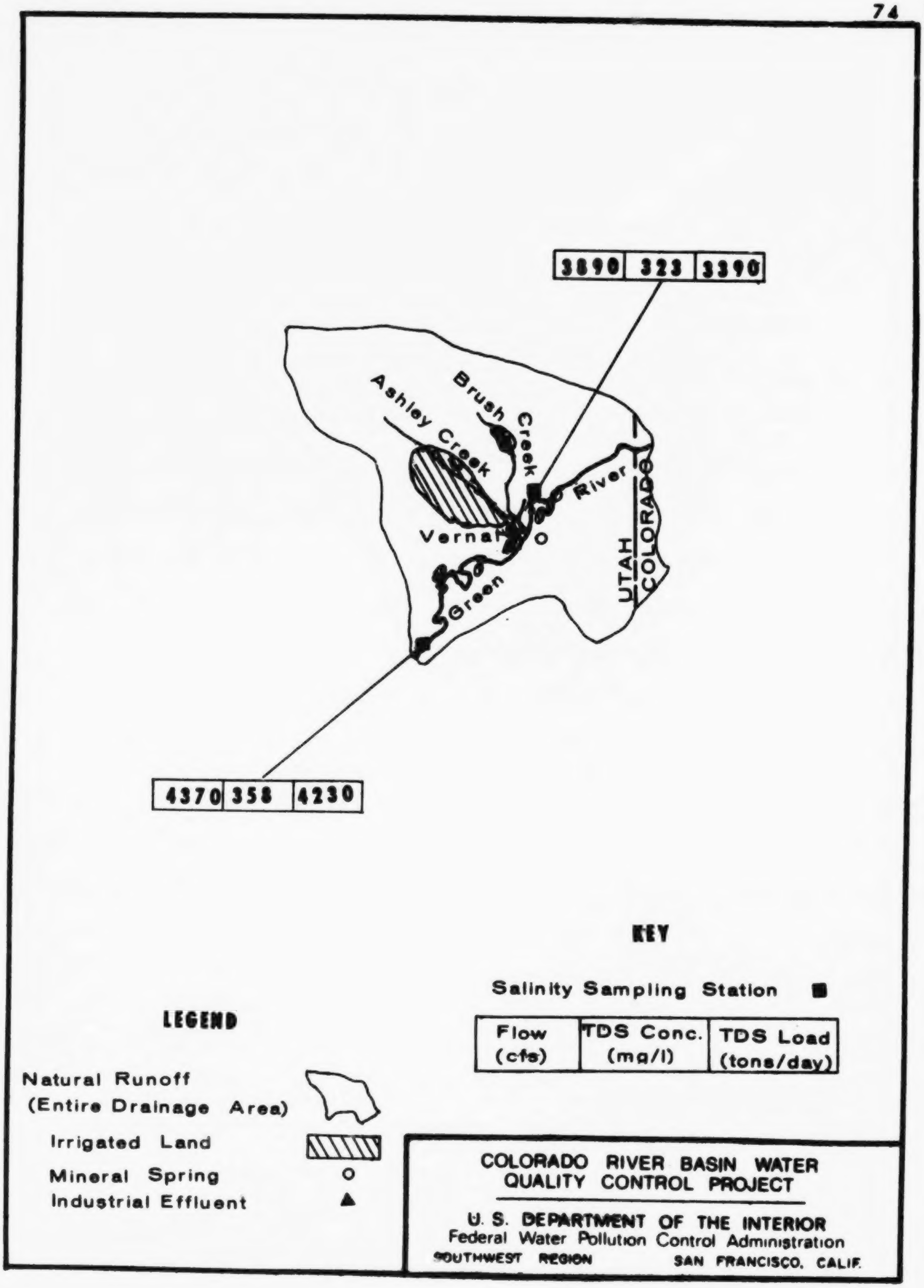
3890 | 323 | 3390
Brush Creek
Ashley Creek
River
Vernal
Green
UTAH
COLORADO
4370 | 358 | 4230
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Mineral Spring ○
Industrial Effluent ▲
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Figure 23 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 7, Upper Colorado River Basin, 1965-66

The predominantly clacium-bicarbonate composition of Brush Creek during runoff months was characteristic of headwater streams in the Upper Basin. Large increases in mineral concentrations occurred during the irrigation season with sulfate being the prevalent anion. During the winter months, sodium and sulfate decreased, although sulfate remained the predominate anion. The high sulfate concentrations resulted from solution of gypsum by overland runoff and irrigation waters.

Water quality data on Ashley Creek watershed developed by the Bureau of Reclamation for the period 1957-1965 were included in the study. During water years 1959, 1960, and 1961, irrigation of 20,000 acres in Ashley Valley contributed approximately 50 tons of salt per day to Ashley Creek. In water year 1962 the salt load increased to more than 100 tons per day. In 1963, the salt load was only 60 tons per day and declined to approximately 30 tons per day for water year 1964. In water year 1965 the salt load was 100 tons per day. The salt load during the Project study period, June 1965 to May 1966, was computed to be approximately 230 tons per day, or an average of 4.2 tons per acre. The heavy snow pack in 1965 produced abundant runoff and local irrigators applied large amounts of water which undoubtedly leached out salts which had accumulated in the soils during the previous dry years.

Several salt springs and other sources of saline ground-water added to the salt load of the Green River in Area 7. Split Mountain Warm Springs, located in Dinosaur National Monument, are reported to contribute 51 tons of salt per day. These Springs have been inaccessible since the impoundment of Flaming Gorge Reservoir.

Water produced at the Ashley Valley Oil Field along the lower reaches of Ashley Creek is released to Ashley Creek for irrigation use. The water from the oil field contributed 32 tons of salt per day to the system. An oil-test hole located adjacent to U. S. Highway 40, east of Jensen, Utah, discharges 100 gallons per minute with a TDS concentration of 1,800 mg/l. This water is used for stock watering and was not included in the area budget.

Magnesium and sulfate ions increase in proportion to the other principal ions in the Green River as a result of irrigation return flows (Figure 48).

The salt budget for Area 7 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Springs	51	5.6
Irrigation	230	25.2
Industrial	32	3.5
Runoff	599	65.7
Total	912	

Study Area 8 (Green River Subbasin)

Description. Area 8 consists of the entire Duchesne River drainage basin, comprising 3,820 square miles located mostly in Duchesne County but including small portions of Uintah and Wasatch Counties in Utah (Figure 24).

Most of the streams originate in the glaciated Uinta Mountains or the high uplands of the Wasatch Plateau. The Uinta Mountains are underlain by crystalline rocks which yield runoff of excellent quality. The Wasatch Plateau is a high rolling upland with deeply incised streams. The area is underlain by marls, shales, and oil shales of the Green River

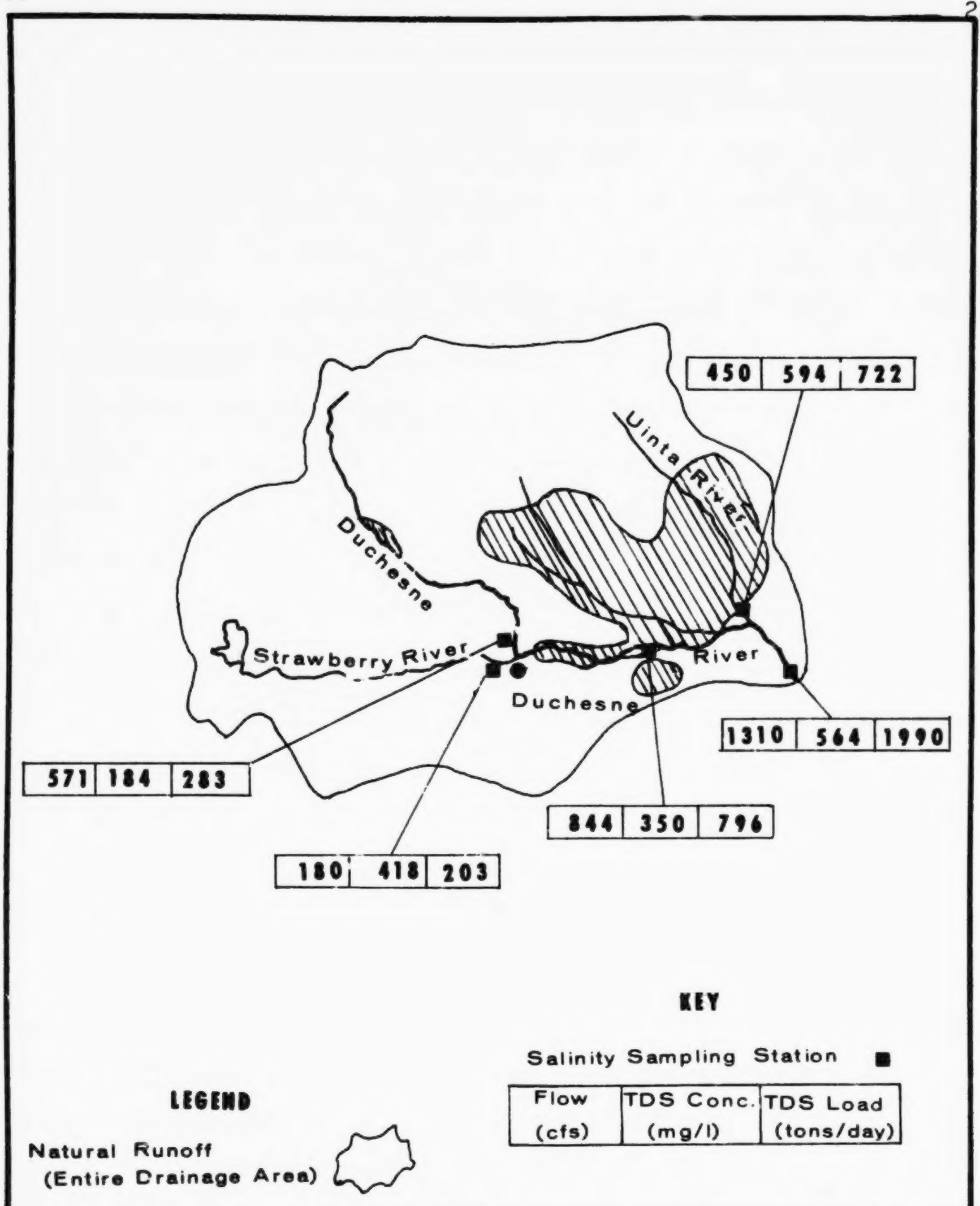
450 594 722
Uinta River
Duchesne
Strawberry River
Duchesne River
1310 564 1990
571 184 283
844 350 796
180 418 203
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF.

Figure 24 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 8, Upper Colorado River Basin, 1965–66

and Uinta formations which contain numerous soluble minerals. The streams flow south to the Uinta Basin crossing sedimentary layers en route. The valley floor, which covers the greater part of the study area, is underlain with flat-lying Tertiary rock.

Virtually all the runoff in Area 8 is derived from the south flanks of the Uinta Mountains or from headwaters area of the Strawberry River. Together, these areas make up less than 10 percent of Study Area 8.

Findings. Several discrete natural sources discharge minor salt loads to streams within the area. Stinking Springs on the Strawberry River discharges from 20 to 50 gallons per minute of water with a TDS concentration of approximately 7,700 mg/l. These Springs contribute a salt load of approximately 1.3 tons per day. Springs along Indian Creek add 3.3 tons of salt per day to the system.

The 166,000 acres of irrigated land in Area 8 adds approximately 1,350 tons of salt per day to the system. This amounts to an average yield of 3.0 tons per acre per year.

Ionic composition of the headwaters of the Duchesne River was of the characteristic calcium-bicarbonate type (Figure 48). Inflow of poor quality water from the Strawberry River caused increases in the proportions of sodium and sulfate. The composition diagram for the most downstream station on the Duchesne showed the calcium, sodium, sulfate pattern characteristics of a mature stream carrying irrigation return water.

The salt budget for Area 8 is given in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Springs	4	0.2
Irrigation	1350	67.8
Runoff	636	32.0
Total	1990	

Study Area 9 (Green River Subbasin)

Description. Area 9 includes the entire drainage area of the White River and covers approximately 44,000 square miles in Garfield, Rio Blanco, and Moffitt Counties of Colorado; and Uintah County in Utah (Figure 25). The area includes the communities of Meeker and Rangely, and several other smaller settlements. The area has a total population of approximately 5,600.

Main tributaries of the White River include the South Fork of the White River and Piceance, Yellow, Douglas, and Evacuation Creeks. The White River and South Fork of the White River originate on the White River Plateau at elevations over 12,000 feet. This Plateau consists of a series of flat lava flows with glaciated valleys through which the headwater streams flow. Runoff from this Plateau is of good quality. Below Meeker, the river channel cuts through the Grand Hogback and then enters more varied topography consisting of plateaus, ridges, and cliffs, interspersed with open valleys. The varied topography reflects the varying erosion resistence of the rocks which underlie the area. The easily eroded formations in the lower elevations yield small amounts of mineralized water.

Findings. During the study period, the White River at Buford discharged a mean flow of 352 cfs and a mean salt load of 157 tons per day. The South Fork of the White River at Buford yielded a mean flow of 310 cfs and a mean salt load of 115 tons per day. These two streams which originate on the White River Plateau contributed more than two-thirds of the total runoff, but less than one-fourth of the salt load from Area 9.

An increase of 30 cfs and 70 tons of salt per day was measured downstream at the Coal Creek station. Almost all of the increase in flow and

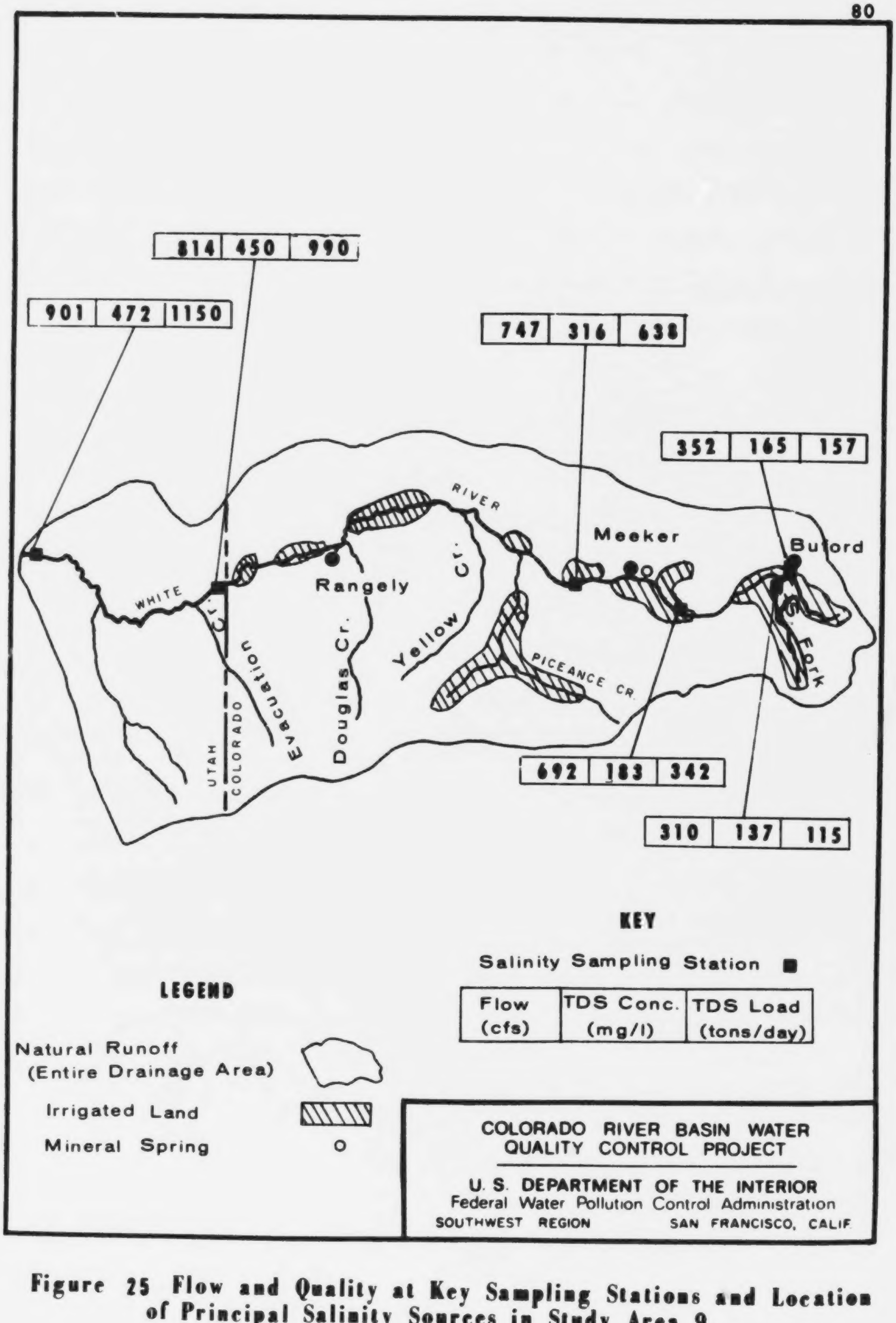
814 | 450 | 990
901 | 472 | 1150
747 | 316 | 638
352 | 165 | 157
692 | 183 | 342
310 | 137 | 115
WHITE
RIVER
Cr.
Rangely
Meeker
Buford
Yellow Cr.
Douglas Cr.
Evacuation
PICEANCE CR.
S. Fork
UTAH
COLORADO
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Mineral Spring ○
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
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Figure 25 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 9, Upper Colorado River Basin, 1965–66

salt load resulted from tributary inflow to the reach. The effect on water quality, of irrigation of approximately 10,000 acres within the White River reach between Buford and Coal Creek, was virtually nil. Soils within this reach have been well leached by abundant precipitation. No significant changes in chemical composition were observed between the Buford and Coal Creek stations.

Increases of 55 cfs and 296 tons of salt per day occurred between the Coal Creek and Meeker stations on the White River. An abandoned oil-test hole near Meeker contributed 3.1 cfs of water with a dissolved solids concentration of approximately 19,000 mg/l. This accounted for approximately 160 tons per day of the salt load increase within this reach. The remaining flow of 52 cfs and a salt load of 136 tons per day within the reach was from undefined sources. Irrigation of approximately 10,000 acres within the same reach yields an undetermined quantity of salt to the stream, but it is believed to be considerably less than the 136 tons per day from undefined sources.

In the past, water flowed from a test hole located on the mesa to the north of the White River. Salt water also flowed from a seismic shot hole until it was recently plugged. Thus, it is evident that saline water in the near surface formations east of Meeker is under artisian pressure and may be moving into the stream through naturally occurring fissures or other test holes.

Chemical composition changes in the White River reach between Coal Creek and Meeker tends to substantiate that salt load increases are caused by ground-water inflow. Sodium, chloride, and sulfate were the predominate ions in discharge from the Meeker oil-test hole. These ions increased markedly in the immediate reach of the White River.

Flow and salt load at the USGS station on the White River at Watson reflect an increase of 67 cfs and 352 tons of salt per day in the reach of the stream below Meeker. Approximately 100 tons per day of this increase is discharged from the Piceance Creek drainage area. This includes the salt contribution from irrigation of approximately 5,000 acres along Piceance Creek. A flowing oil-test hole along Piceance Creek added 17 tons of salt per day.

The salt load from Yellow Creek was approximately 7 tons per day. This included approximately 2 tons of salt per day from a sulfur spring located above the mouth of Yellow Creek. The TDS concentration in Yellow Creek exceeded 2,000 mg/l throughout the year. The salt load from Douglas Creek varied widely with flow, but was estimated to average 35 tons per day. Approximately 20 tons of salt per day were added by irrigation of small areas along the White River below Meeker.

The saline inflow from Piceance, Yellow, and Douglas Creeks caused major changes in chemical composition of the White River (Figure 48). Sodium, sulfate, and bicarbonate increased significantly below the entrance of these streams. Relatively small changes in salt loads and chemical composition were observed in the White River between Watson and Ouray, Utah.

The salt budget for Area 9 is given in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Irrigation	20[1/]	1.7
Abandoned oil-test holes	177	15.4
Springs	2	0.2
Runoff	951[1/]	82.7
Total	1150	

[1/] Includes salt contribution from irrigated areas along Piceance, Yellow, and Douglas Creeks.

Study Area 10 (Green River Subbasin)

Description. Area 10 includes the Green River drainage area between the mouth of the White River and the town of Green River, Utah (Figure 26). The area covers approximately 3,000 square miles in Grand, Emery, Carbon, Uintah, and Duchesne Counties of Utah. Major tributaries in the area include Willow Creek, Pariette Draw, Nine-Mile Creek (Minnie Maud Creek), and the Price River. There are no communities and few inhabitants within the area.

The Green River flows from the Uinta Basin toward the east side of the San Rafael Swell, cutting through the Roan Cliffs and Book Cliffs in Desolation Canyon. In the Uinta Basin, the rocks are flat lying and form broad flat valleys and mesas. In the Desolation Canyon area, streams are deeply incised with small flat mesas remaining. As the river flows south, it crosses progressively older rocks from the Tertiary sediments in the Ouray, Utah, area to the Mancos shale at Green River, Utah. The Book Cliffs are formed by the late Cretacious Mesa Verde group and Roan Cliffs are formed by the oil shales of the Green River formation. Runoff from all formations within the area is moderately to highly mineralized. The mean annual runoff from Area 10 is negligible except during snowmelt and infrequent summer storms.

Findings. During the study period, total flow within the area decreased by 66 cfs while the salt load increased by 510 tons per day. The total salt load added by Pariette Draw, Willow Creek and Nine-Mile Creek accounted for more than half of the salt load increase within the reach. The remaining increase was derived from minor tributaries and from direct runoff to the Green River. Virtually the entire salt load from Area 10 was attributable to natural runoff.

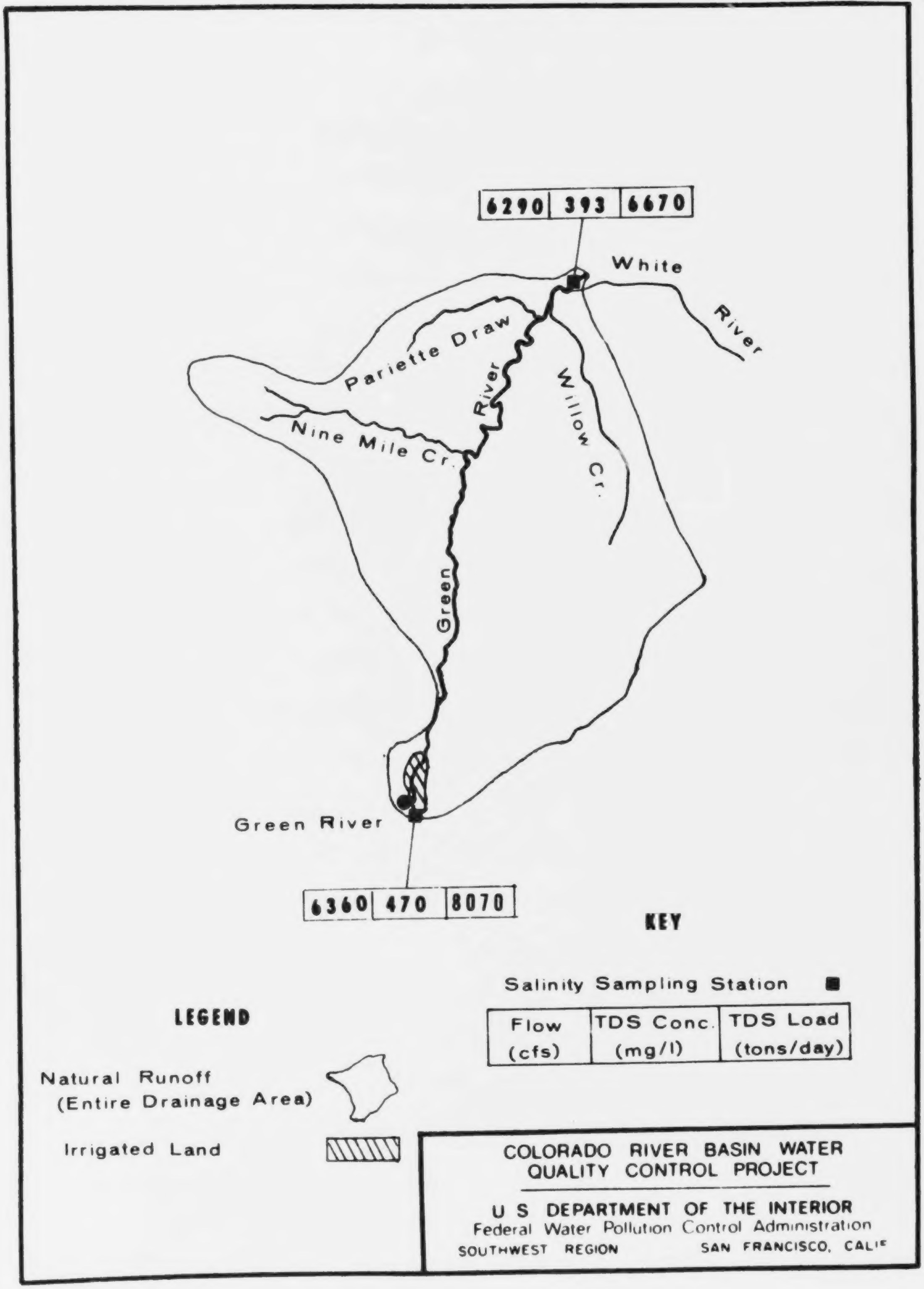
6290
393
6670
White
River
Pariette Draw
River
Willow Cr.
Nine Mile Cr.
Green
Green River
6360
470
8070
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
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Figure 26 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 10, Upper Colorado River Basin, 1965–66

Study Area 11 (Green River Subbasin)

Description. Area 11 includes the entire Price River drainage basin, which covers approximately 1,900 square miles in western Carbon and northern Emery Counties of Utah, and small portions of adjacent counties. The communities of Castle Gate, Helper, Price, Wellington, Draggerton, and numerous smaller settlements are located in the area. (Figure 27)

Most of the runoff in the area originates along the east flank of the Wasatch Plateau, which forms the western boundary of the area. The Price River crosses the Book Cliffs, flows across Castle Valley, the source of most of the salt load in the Price River, then across the San Rafael Swell and across the Book Cliffs again, to join the Green River. The area downstream of Castle Valley yields little flow or salt, except during snowmelt or summer storms.

Findings. During the study period, the Price River at Woodside, Utah, carried a mean flow of 136 cfs and a mean salt load of 885 tons per day. Irrigation in the San Rafael River area contributed approximately 100 tons of salt per day. Runoff above the diversion dam near Price, Utah, yielded approximately 100 tons of salt per day. A coal washing plant[1] and a dry ice manufacturing plant on Flood Wash near Wellington yielded 13 tons of salt per day. Municipal discharges added 3 tons of salt per day. The small tributaries and direct runoff below Price contributed approximately 80 tons of salt per day. The total measured salt load from Area 11 was approximately 300 tons per day leaving some 580 tons per day attributable to influent ground-water and irrigation.

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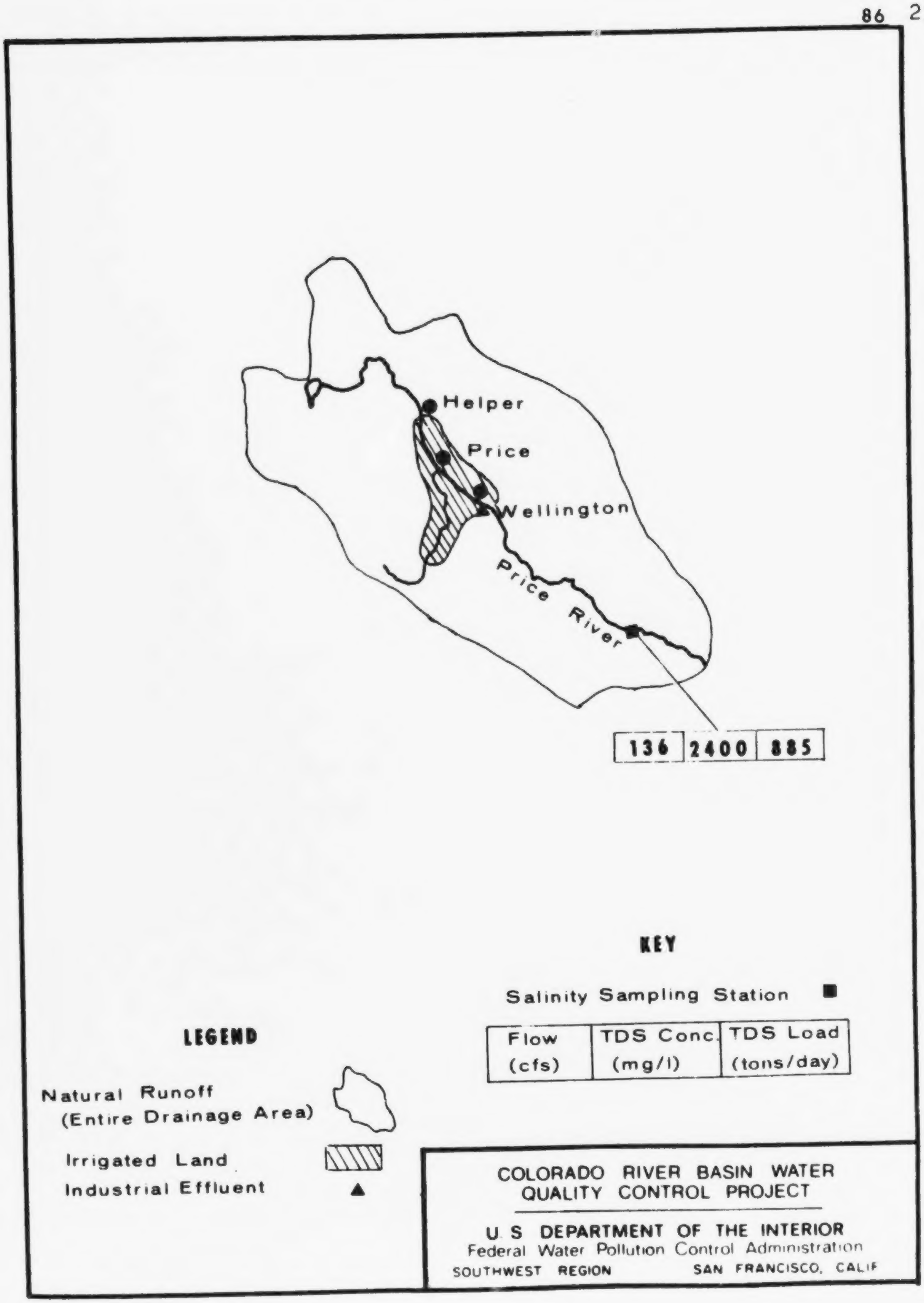
[1] The coal washing plant ceased operations subsequent to completion of this study.


Helper
Price
Wellington
Price River
136
2400
885
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Industrial Effluent ▲
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
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Federal Water Pollution Control Administration
SOUTHWEST REGION
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Figure 27 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 11, Upper Colorado River Basin, 1965–66

Very intensive study of ground-water conditions would be required to define the relative amounts of salt contributed by naturally occurring effluent ground-water and irrigation. If most of the unmeasured salt load was due to irrigation of the 25,000 acres in Castle Valley, the average yield would be on the order of 8.5 tons per acre per year. In any event, the application of irrigation water on the outcrop of Mancos shale severely degrades mineral quality of the Price River.

The effect of leaching of soils underlain by Mancos shale is reflected in the composition pattern diagram for the Price River at Woodside (Figure 48). The TDS concentration was very high with sulfate being the predominate anion. Concentrations of all cations were high, with sodium exceeding all others. Although discharge from the Price River is small compared to flow in the Green River, concentrations of sulfate and sodium in the Price River were sufficiently high to cause significant alteration in the chemical composition of the Green River.

The salt budget for Area 11 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Irrigation (Castle Valley)	580[1/]	65.5
Irrigation (San Rafael River)	100	11.3
Industrial	13	1.5
Municipal	3	0.3
Runoff	189	21.4
Total	885	

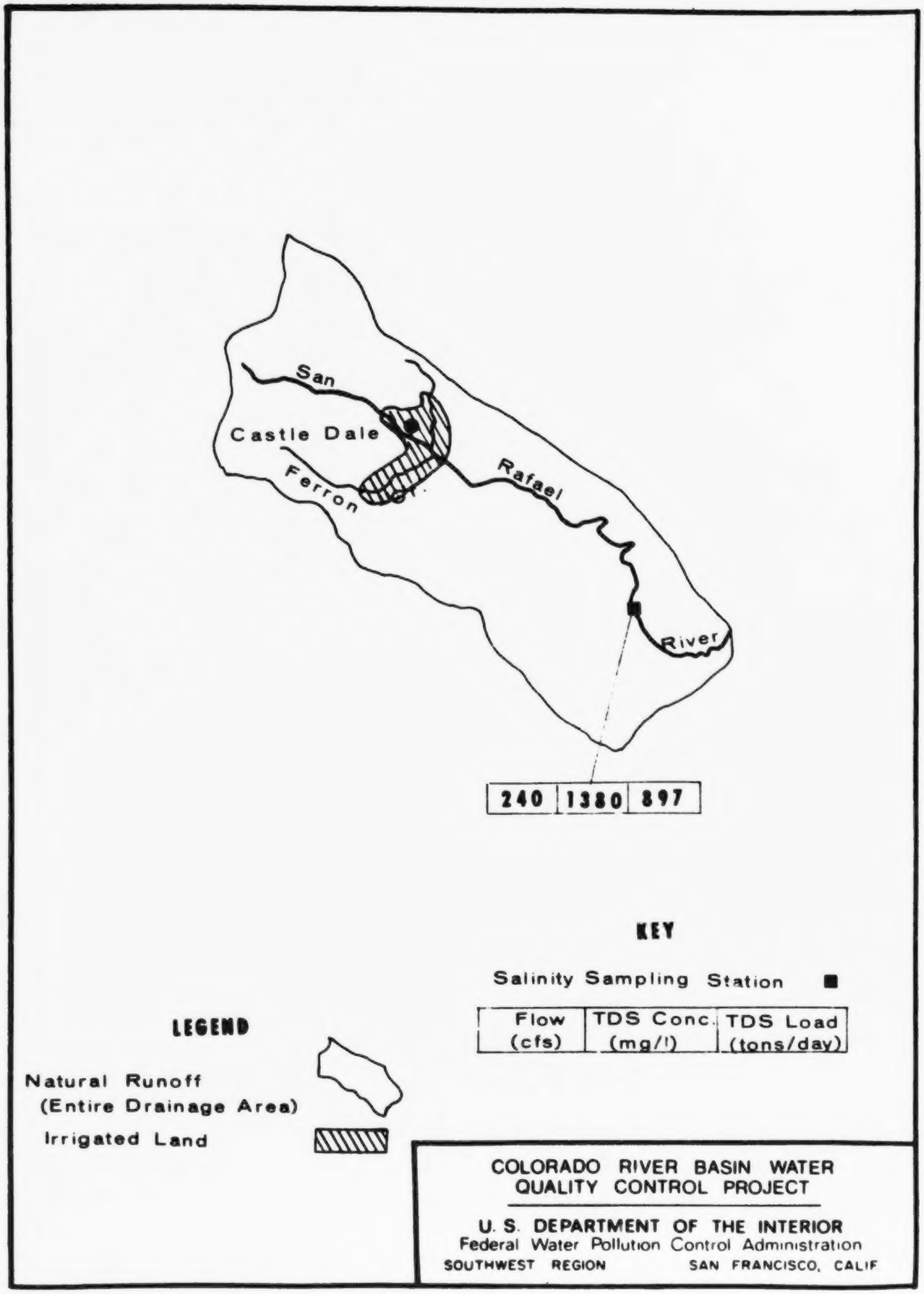
[1/] Includes effluent ground-water which cannot be quantified without extensive ground-water study.

Study Area 12 (Green River Subbasin)

Description. The study area is the San Rafael River drainage basin, including approximately 2,065 square miles in Emery and Sanpete Counties of Utah. There are no communities of sufficient size to have significant effect on mineral quality of water within the area. Rainfall within the area ranges from less than 8 inches per year at the lower altitudes to more than 40 inches per year in the higher altitudes. Virtually all the runoff from Area 12 is derived from streams which head in the uplands of the Wasatch Plateau, along the western edge of the study area. The streams then flow into the relatively flat Castle Valley which is underlain by the highly soluble Mancos shale. Most of the headwater streams are intercepted by the San Rafael River in the Castle Valley area. The San Rafael River crosses the San Rafael Swell which is underlain by sediments of the Morrison formation of the San Rafael group. These formations include thick beds of gypsum, but yield small amounts of runoff except during periods of snowmelt. The San Rafael River then crosses the relatively flat San Rafael desert and joins the Green River below Green River, Utah. The San Rafael watershed downstream of Castle Valley Yields relatively small amounts of runoff and salt due to the low annual precipitation. (Figure 28)

Findings. Two minor sources, Iron Wash Spring and Buckhorn Wash Spring contributed approximately 0.5 ton of salt per day to the stream system.

The Bureau of Reclamation collected extensive data on water quality in the Castle Valley area during the period 1962-1965. These data were


San
Rafael
River
Castle Dale
Ferron Cr.
240 | 1380 | 897
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
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SAN FRANCISCO, CALIF

Figure 28 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 12, Upper Colorado River Basin, 1965–66

combined with quality data collected by the Project in developing the salt budget for the area. Irrigation of 36,000 acres in Castle Valley added a salt load of approximately 290 tons per day, a portion of which is returned to the Price River. The average yield of approximately 2.9 tons per acre per year closely approximates the 3.2 tons per acre per year calculated by Iorns and his associates.(4) Runoff, the major salinity source in the area, increased the salt load from the area by 607 tons per day.

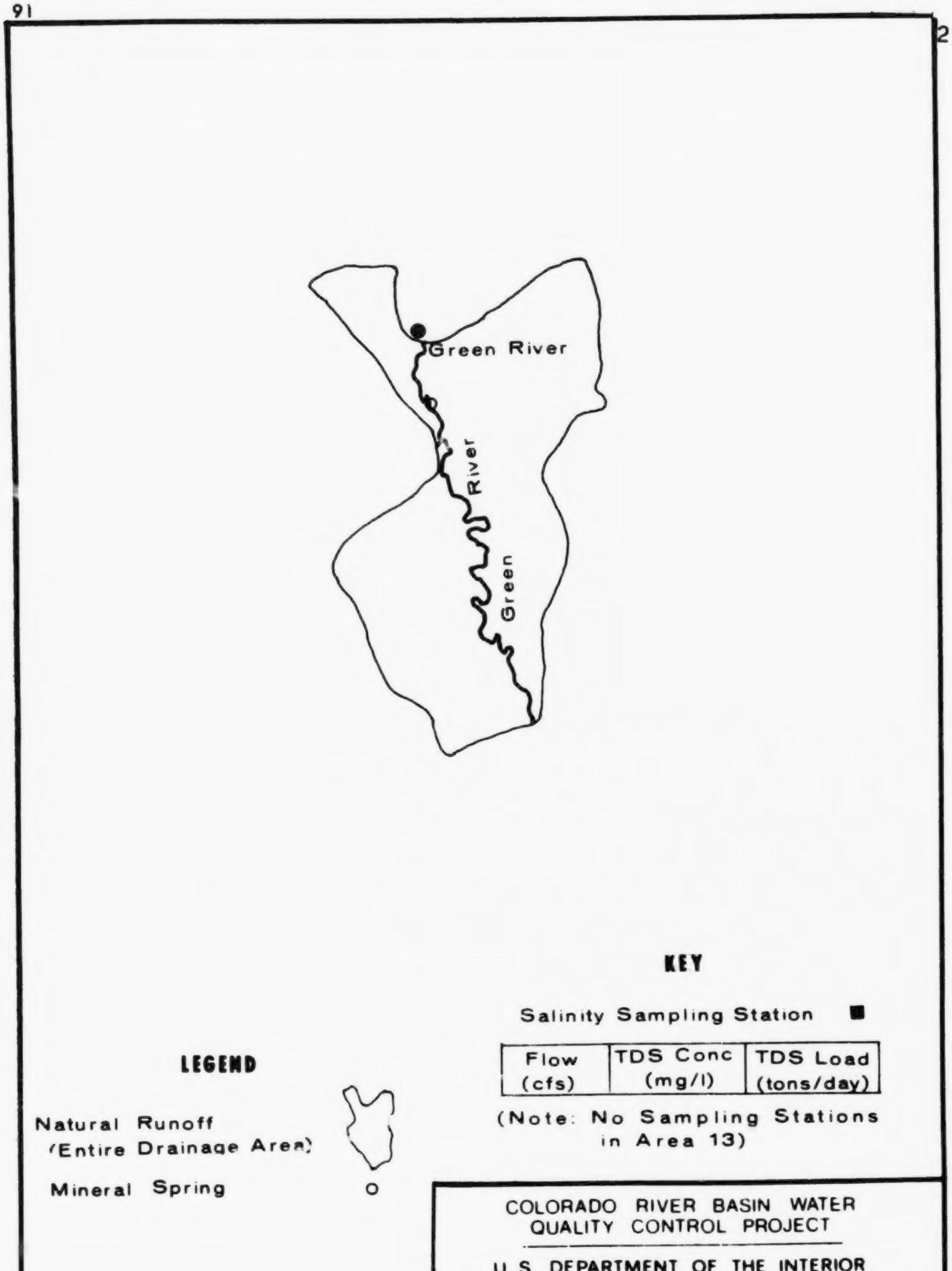
Chemical composition of the San Rafael River is similar to that of the Price River with sulfate being the major anion (Figure 48). Nearly equal amounts of calcium, magnesium, and sodium indicate that solution of gypsum from Mancos shale, by precipitation and applied irrigation water, is responsible for a major portion of the salt load input from this area.

The salt budget for Area 12 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Springs	<1	0.1
Irrigation	290	32.3
Runoff	606	67.6
Total	897	

Study Area 13 (Green River Subbasin)

Description. Area 13 consists of the Green River drainage below the town of Green River, Utah, exclusive of the San Rafael River drainage area (Figure 29). It covers approximately 1,900 square miles in parts of San Juan, Wayne, Grand, and Emery Counties in Utah. The community


Green River
Green River
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc (mg/l)
TDS Load (tons/day)
(Note: No Sampling Stations in Area 13)
LEGEND
Natural Runoff (Entire Drainage Area)
Mineral Spring ○
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
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Federal Water Pollution Control Administration
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Figure 29 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 13. Upper Colorado River Basin, 1965–66

of Green River and the small village of Thompson are the only population centers in the area.

The study area is located in the "Canyon Lands" section of the Colorado Plateau, an area characterized by young to mature canyon plateaus with high relief. The northern portion of the area is underlain by Mancos shale. In the southern portions of the area, streams have cut deep canyons into the sandstones and shales of the San Rafael Group and the Dakota and Morrison formations, which yield moderately mineralized runoff. The Green River crosses the Little Grand fault downstream of the town of Green River. In the geologic past, the Little Grand fault served as a passageway for the upward migration of mineralized ground-water prior to the drilling of a test hole, "Crystal Geyser," which currently serves to relieve the driving pressure.

Findings. "Crystal Geyser" is the only known point source of salt in Area 13. This "geyser" erupts periodically as carbon dioxide pressure buildup in the originating formation exceeds the head required to expel accumulated water from the test hole. This source adds a salt load of 53 tons per day directly to the Green River.

The reach of the Green River immediately above its mouth is inaccessible; therefore, no outflow station for Area 13 could be established. Although it was not possible to develop a budget for this study area, mineral contributions within the area are believed to be insignificant. No perennial streams enter the Green River in Area 13, but Browns Wash and Salaratos Wash, both of which drain Mancos shale outcrops, discharge highly mineralized water during infrequent storms.

Study Area 14 (Upper Main Stem)

Description. Area 14 consists of the Colorado River drainage above the mouth of the Eagle River, which covers 3,480 square miles in Grand, Routt, Eagle, and Summit Counties of Colorado. The communities of Hot Sulphur Springs, Granby, Grand Lake, Kremmling, and other small settlements are located within the area (Figure 30).

Streams in Area 14 originate along the Continental Divide, in and south of Rocky Mountain National Park. The headwater areas are underlain by insoluble granitic formations. Elevations range from approximately 6,300 feet at Dotsero, to more than 13,000 feet at the Continental Divide. Precipitation varies from approximately 12 inches per year at the lower elevations, to more than 40 inches per year at higher elevations.

Findings. During the period of the study, the Colorado River drainage area above Hot Sulphur Springs, Colorado, yielded a mean annual flow of 230 cfs and a mean salt load of 57 tons per day. In general, runoff from the pre-Cambrian crystalline rocks and the Tertiary volcanics above Granby was of very good quality. Irrigation added little salt due to the low solubility of the soil. Flow and salt load contributions to the Colorado River above Hot Sulphur Springs, due to runoff, were 232 cfs and 40 tons per day. Irrigation of mountain meadows and forage crops in the tributary area above Hot Sulphur Springs added 15 tons of salt per day to the Colorado River.

The thermal springs, for which the town of Hot Sulphur Springs is named, contributed approximately 0.4 tons of salt per day to the Colorado

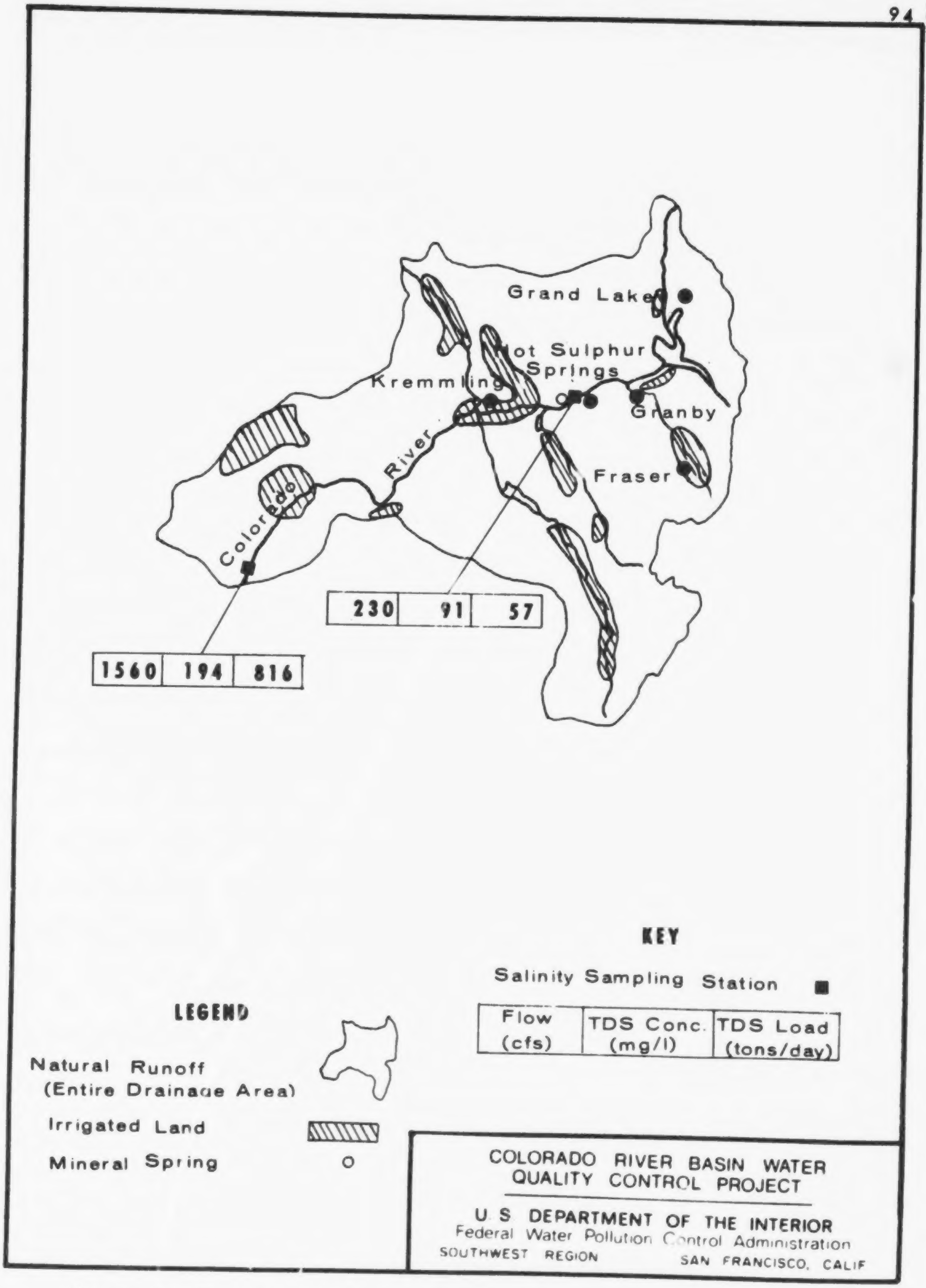
Grand Lake
Hot Sulphur Springs
Kremmling
Granby
Fraser
Colorado River
230 | 91 | 57
1560 | 194 | 816
KEY
Salinity Sampling Station ■
Flow (cfs) | TDS Conc. (mg/l) | TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Mineral Spring ○
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Figure 30 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 14. Upper Colorado River Basin, 1965–66

River. In the reach between Hot Sulphur Springs and Kremmling the increase in mean flow and salt load amounted to 25 cfs and 92 tons per day. Tributaries within this reach include Williams Fork, Reeder Creek, Troublesome Creek, East Troublesome Creek, Muddy Creek, and the Blue River. These tributaries add approximately 30 tons of salt per day to the Colorado River. Irrigation of approximately 24,000 acres in the Colorado River Valley, upstream of Kremmling, added 61 tons of salt per day to the stream system. This yield averages 0.9 tons per acre per year.

The Muddy Creek drainage area contributed a total salt load of 82 tons per day of which 32 tons per day were from runoff, and 46 tons were attributable to the irrigation of 7,000 acres within the Muddy Creek area. The salt yield from irrigation averaged 2.4 tons per acre per year.

Flow and salt load increases in the Colorado River between Kremmling and the mouth of the Eagle River were 588 cfs and 474 tons per day, respectively. These figures indicate the low mineral content of runoff from this area and are directly related to the insoluble character of the rock which outcrops throughout much of the tributary area.

Chemical composition of the Colorado River at Hot Sulphur Springs was typical of a headwater stream. The shape of the composition diagram is roughly triangular, with calcium and bicarbonate concentrations predominant, and sodium and chloride present only in small amounts (Figure 47). Downstream stations show an increase in the proportions of magnesium and sulfate concentrations due to the influence of irrigation return flows.

The salt budget for Area 14 is given in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Springs	<1	0.1
Irrigation	122	14.9
Runoff	694	85.0
Total	817	

Study Area 15 (Upper Main Stem)

Description. Area 15 includes the drainage areas of the Eagle and Roaring Fork Rivers and the Colorado River watershed between the mouth of the Eagle River and the USGS gage at Silt, Colorado (Figure 31). The area covers some 3,200 square miles in Eagle, Garfield, Pitkin, and Mesa Counties of Colorado. The communities of Glenwood Springs, Aspen, and several other smaller settlements are located in the area.

The higher mountain areas are underlain by resistant, insoluble rock formations which yield large volumes of high quality water. The valleys of the Eagle River below Gypsum and the Roaring Fork River between Carbondale and Glenwood Springs are cut into more easily eroded rock including the gypsum and anhydrite of the Paradox formation. These lower areas receive less precipitation and yield smaller quantities of runoff, but ground-water and runoff from these areas are highly mineralized.

Findings. The Eagle River upstream of Redcliff, Colorado, contained TDS concentrations of 120 mg/l, or less, throughout the year of study. Cross Creek above Minturn, Colorado, had TDS concentrations of less than 50 mg/l. These low concentrations of TDS demonstrate the insoluble character of the bedrock underlying the headwater areas.

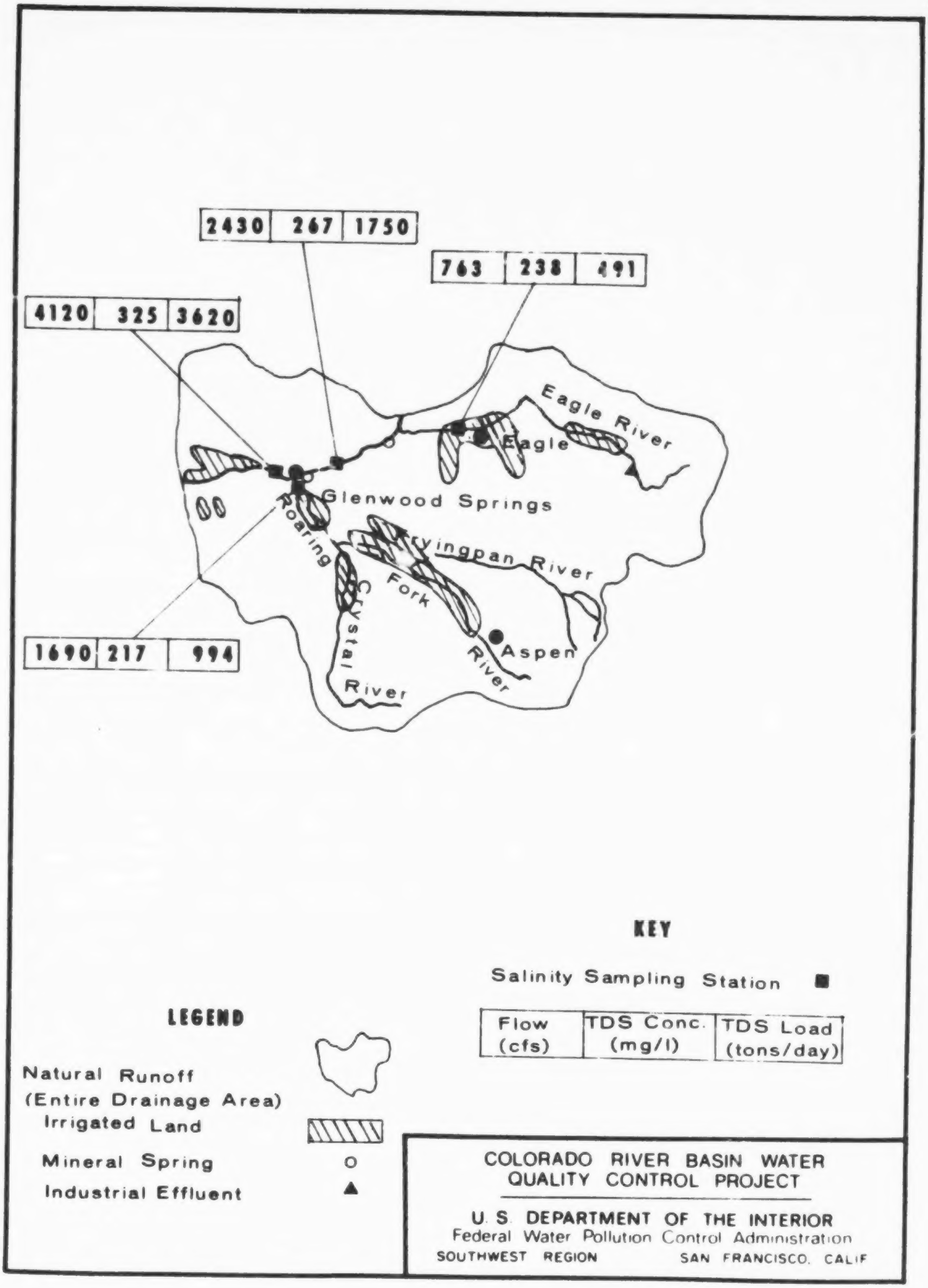
2430 | 267 | 1750
763 | 238 | 491
4120 | 325 | 3620
1690 | 217 | 994
Eagle River
Eagle
Glenwood Springs
Roaring Fork
Fryingpan River
Crystal River
Aspen
River
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
Mineral Spring ○
Industrial Effluent ▲
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Figure 31 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 15. Upper Colorado River Basin, 1965–66

The New Jersey Zinc Corporation mine and mill at Gilman, Colorado, discharges process waste to a tailings pond located near the mouth of Cross Creek. The decanted tailings liquor is discharged into Cross Creek, and adds approximately 10 tons of salt per day to the stream system. Ground-water moving through an old tailings area, at this location, also picked up acid and dissolved metals which were then carried into the Eagle River. The toxic materials which entered Eagle River and Cross Creek eliminated aquatic life in the immediate reaches of both streams. Since the completion of the study, the New Jersey Zinc Corporation has installed pumps which collect and return the toxic seepage to the tailings area.

Salt load in the Eagle River at Edwards, Colorado, varied from 130 tons per day during the winter months to more than 600 tons per day during the spring runoff period. Much of this salt load is contributed by ground-water seeping from mineralized formations which outcrop in the area, and leaching from irrigated areas underlain by saline formations upstream of Edwards. It was not possible to separate these ground-water and irrigation effects. Brush Creek, another Eagle River tributary, contributed approximately 60 tons of salt per day, of which approximately 10 tons per day were from small irrigated areas. The remainder of the salt load was due to natural runoff from the outcrop of the highly saline Paradox formation.

The quality of Gypsum Creek was determined at its mouth at Gypsum, Colorado, but it was not possible to obtain accurate flow measurements at this point; therefore, no salt load contribution could be calculated.

Total dissolved solids concentrations at the mouth of Gypsum Creek ranged from 400 to 1,250 mg/l during the study period. These concentrations were observed below an area underlain by gypsum of the Paradox formation and downstream of 6,400 acres of irrigated land.

The salt load of the Eagle River above the mouth of Gypsum Creek was 491 tons per day during the study period. The salt load contribution by Gypsum Creek is not included in this total. A total salt load increase of 938 tons per day occurred within the reach of the Colorado River in Study Area 15. Mineral springs, located on both banks of the Colorado River approximately 2½ miles below the mouth of the Eagle River, and minor tributary inflow, appeared to be responsible for virtually all of the 447 tons of salt per day increase which is not otherwise accounted for.

Thermal springs in the vicinity of Glenwood Springs added 11.5 cfs and 585 tons of salt per day to the Colorado River. Flow from one of the major springs, not included in the above total, is used in a large outdoor swimming pool at Hot Springs Lodge in Glenwood Springs. Flow from this spring is also used to heat the lodge and to convey raw sewage from the lodge to the Colorado River. Discharge from the lodge was 7 cfs and the salt load was calculated at 333 tons per day. Mineral springs located in the area below Eagle River and above the mouth of Roaring Fork River add a salt load of approximately 1,360 tons per day to the stream system.

During the year of study, the Roaring Fork drainage area yielded a mean flow of 1,694 cfs, and a salt load of 994 tons per day. The drainage area of Roaring Fork River above Basalt yielded 64 percent of the flow, but only 39 percent of the salt load. The Fryingpan River above Basalt yielded 18 percent of the flow but only 7.5 percent of the salt load in the Roaring Fork drainage area. Crystal River at Carbondale yielded 26 percent of the flow in the Roaring Fork system, and 19 percent of the salt load. Direct runoff to the Roaring Fork River from small tributaries and ground-water inflow was calculated to yield 145 tons of salt per day. Irrigation of 21,000 acres in the Roaring Fork drainage area contributed a salt load of 200 tons per day or an average of 3.5 tons per acre per year. This irrigation occurs on lands underlain by saline material derived largely from the Paradox formation.

In the reach of the Colorado River between the mouth of Roaring Fork River and the USGS gage at Silt, increases of 136 cfs and 212 tons of salt per day were observed. Approximately 25 cfs and 16 tons per day of these increases were attributable to runoff in Canyon Creek. Elk Creek yielded approximately 50 cfs and 40 tons of salt per day. Natural runoff contributed approximately 56 tons of salt per day and irrigation of 16,000 acres contributed approximately 100 tons per day to the Colorado River. The salt yield from irrigation averaged approximately 2.3 tons per acre per year.

The chemical composition of the Eagle and Roaring Fork Rivers was very similar and reflected the influence of outcrops of gypsum and anhydrite of the Paradox formation over which the streams flow. The composition pattern diagrams for the Colorado River show increases in chloride and sodium due to the springs at Dotsero and Glenwood Springs (Figure 47). The mineral springs in this area also add radioactive elements to the river system.

The salt budget for Study Area 15 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Industrial Effluents	10	0.3
Springs	1,360	44.4
Runoff	1,384	45.2
Irrigation	310	10.1
Total	3,064	

Study Area 16 (Upper Main Steam)

Description. Area 16 includes the drainage area of the Colorado River between the USGS gages at Silt and Cameo, Colorado. The area covers 1,375 square miles in Garfield and Mesa Counties of Colorado. The significant tributaries within the area are Rifle, Parachute, and Roan Creeks. Rifle which had a 1960 population of 2,135 is the principle community in the area. Elevations range from less than 5,000 feet to more than 11,000 feet. Precipitation varies from about 12 to more than 30 inches per year.

With the exception of minor mesa areas along the south boundary of the study area and the headwaters of East Rifle Creek, Area 16 is underlain by sediments containing saline minerals which result in mineralized runoff. (Figure 32)

Findings. During the year of the study, flow within Area 16 increased by 240 cfs and 490 tons of salt per day were added to the system. Approximately one ton of the load was contributed by sewage effluents from the towns of Rifle and Silt. Forty tons of salt per day were added by effluent from the Union Carbide Nuclear Corporation uranium mill at Rifle, Colorado. An additional undetermined amount of salt was added by seepage from the tailings pond at this location. The mill is located on highly pervious Colorado River alluvium and much of the process water from the mill is discharged into ponds constructed on this alluvium. Water from

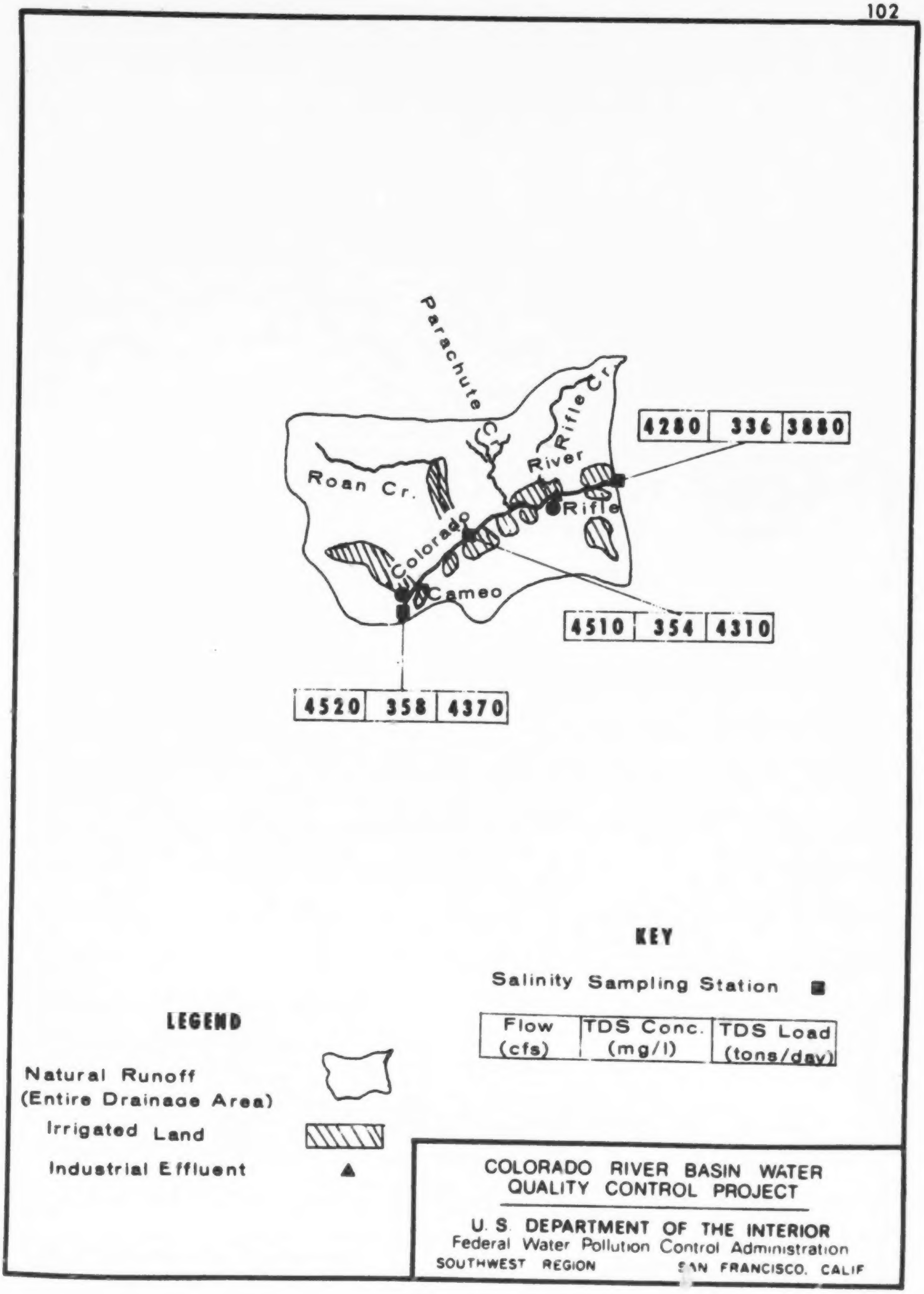
Parachute Cr.
Rifle Cr.
River
Roan Cr.
Rifle
Colorado
Cameo
4280 | 336 | 3880
4510 | 354 | 4310
4520 | 358 | 4370
KEY
Salinity Sampling Station ■
Flow (cfs) | TDS Conc. (mg/l) | TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Industrial Effluent ▲
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Figure 32 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 16, Upper Colorado River Basin, 1965–66

the ponds infiltrates to the ground-water body and moves downgrade to intersect the river. Determination of the salt load added by this seepage would require further investigation of ground-water conditions in the mill area.

During the study period, TDS concentrations in Roan Creek near DeBeque varied from 600 mg/l to 1,700 mg/l with most values ranging between 800 and 850 mg/l. TDS concentrations at the mouth of Roan Creek ranged from 1,200 to 2,400 mg/l. During most of the study period the salt load in Roan Creek near DeBeque, above the irrigated area, was greater than the salt load in Roan Creek at its mouth. This loss indicated that irrigated areas within the reach may have been storing salt. The negative salt balance resulted from an insufficient application of irrigation water to leach the salt.

Only minor changes in chemical composition of the Colorado River occurred within Area 16. There was a slight increase in sulfate concentration in proportion to other constituents.

The salt budget for Study Area 16 is given in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Irrigation	30	6.1
Industrial Effluent	40	8.2
Runoff and Industrial Wastes[1/]	420	85.7
Total	490	

Study Area 17 (Upper Main Stem)

Description. Area 17 consists of the drainage area of the Colorado River between USGS gaging stations near Cameo and near Loma, Colorado,

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[1/] Salt loads contributed by effluent ground-water and seepage from industrial waste ponds in the Rifle area could not be separated at the time of the study.

excluding the Gunnison River drainage area. The study area covers approximately 1,866 square miles in Mesa County, Colorado, and Grand County, Utah. Major tributaries which enter this reach of the Colorado River include Plateau, Ashbury, and Salt Creeks. Principle communities within the area and their 1960 population are Grand Junction, 18,694; and Fruita, 1,830. Smaller communities in the area include Loma, Appleton, Clifton, Palisade, Fruitvale, and Cameo (Figure 33).

A major portion of the study area is within the valley carved by the Colorado River and is bounded on the north and west by the Roan Cliffs and Book Cliffs and on the east by the Grand Mesa. Elevations range from less than 4,500 feet at the Loma gaging station to more than 10,000 feet in the headwaters of the Plateau Creek on Grand Mesa.

Quality of runoff is directly related to the underlying rock formations. Grand Valley is underlain by gypsiferous Mancos shale. Groundwater and runoff from this area contain high concentrations of calcium sulfate. The lava capped Grand Mesa yields most of the runoff in Area 17. This runoff is of excellent quality due to the insoluble nature of the lava formations.

Findings. During the study period, direct discharge of effluent from the Climax Uranium Mill at Grand Junction contributed a salt load of 35 tons per day to the system. The "South Sewage Treatment Plant" at Grand Junction contributed approximately 5 tons of salt per day, and the "West Sewage Treatment Plant" added approximately 11 tons per day. Effluent from the American Gilsonite Corporation Plant near Fruita added approximately 9 tons of mineral salts per day to the river. Direct

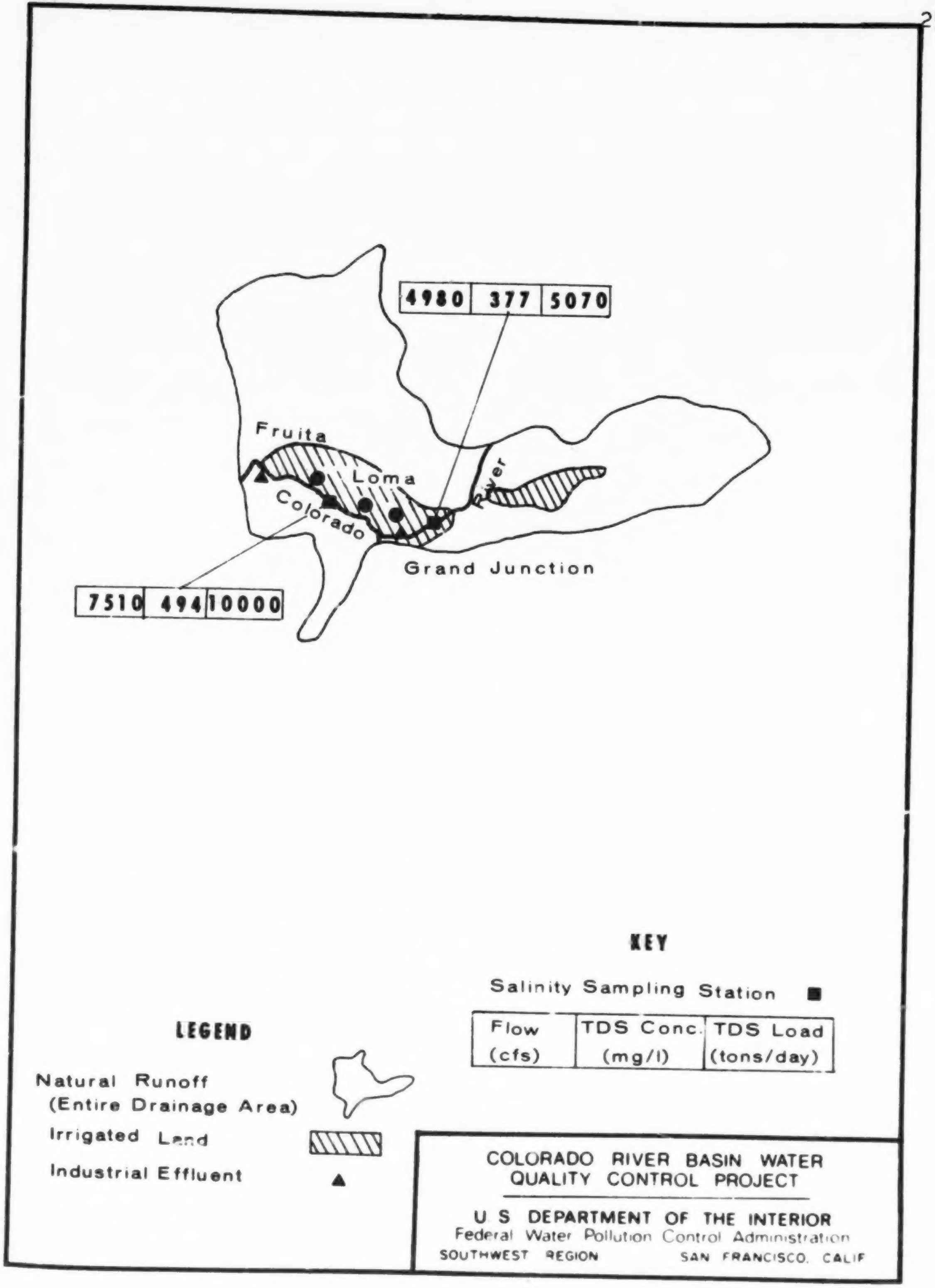
4980
377
5070
Fruita
Loma
Colorado
River
Grand Junction
7510
494
10000
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Industrial Effluent ▲
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Figure 33 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 17, Upper Colorado River Basin, 1965–66

tributary drainage in the immediate valley area added 2 tons of salt per day to the river. Irrigation of approximately 88,000 acres in the Grand Valley area added 1,925 tons of salt per day to the Colorado River, or an average yield of 8.0 tons per day per acre per year. This high salt yield, which is among the largest observed in the Colorado River Basin, is due to the highly soluble nature of the Mancos shale underlying the irrigated area.

Plateau Creek added 161 tons of salt per day to the Colorado River. It was not possible to develop an accurate salt budget for the Plateau Creek drainage, but the salt load contribution by irrigation was estimated at 60 to 82 tons per day. Thus, the total salt contribution for irrigation in Area 17 was approximately 2,000 tons per day. This amounts to 93 percent of the total salt load contribution from Area 17 and 7.7 percent of the total Upper Colorado River Basin salt load.

Chemical composition of the Colorado River within Area 17 changed significantly. Calcium increased slightly, but the relative proportions of cations remained essentially constant. The large increase in sulfate and decrease in chloride concentrations resulted from ion-exchange in the gypsum-rich Mancos soils irrigated with Colorado River water and from similar conditions in the Gunnison River drainage area.

The salt budget for Study Area 17 is tabulated below.

Source	TDS Load (tons/day)	Percent of Total Load
Industrial Effluents	44	2.2
Municipal Effluents	16	0.7
Runoff	90	4.1
Irrigation	2000	93.0
Total	2150	

Study Areas 18, 19, 20, and 21 (Upper Main Stem)

Description. Study Areas 18, 19, 20, and 21, comprising the Gunnison River Drainage, were combined for study as a unit because of the complex water diversions between the areas (Figure 34). The study area covers 8,000 square miles in Mesa, Delta, Gunnison, Saguache, Hinsdale, San Juan, Ouray, and Montrose Counties of Colorado. Delta, Montrose, Gunnison, Ouray, and Paonia are the principle communities in the area.

Major tributaries in the area include Tomichi Creek, Lake Fork, North Fork, and the Uncompahgre River. The headwaters of the Gunnison River, Tomichi Creek, and Lake Fork are underlain by resistant rocks which yield large quantities of high quality runoff; while the areas drained by the North Fork, the Uncompahgre, and the Lower Gunnison River are underlain by more soluble formations which result in more mineralized runoff.

Findings. The Gunnison River discharged a mean flow of 1,040 cfs and a mean salt load of 314 tons per day at Gunnison, Colorado. The salt load from irrigation upstream of Gunnison was 9 tons per day, or 0.3 tons per acre per year. Runoff from the Taylor River, East River, Ohio Creek, and directly to the Gunnison River contributed a mean flow and salt load of 1,085 cfs and 294 tons per day. The excellent quality of this runoff is directly attributable to the resistant nature of the headwaters rock formations.

Salt load budgets for the Razor Creek drainage and the irrigated areas along Tomichi Creek indicated a similar low salt yield from irrigation. The soils which were under irrigation have been well leached by the relatively high precipitation in this area.

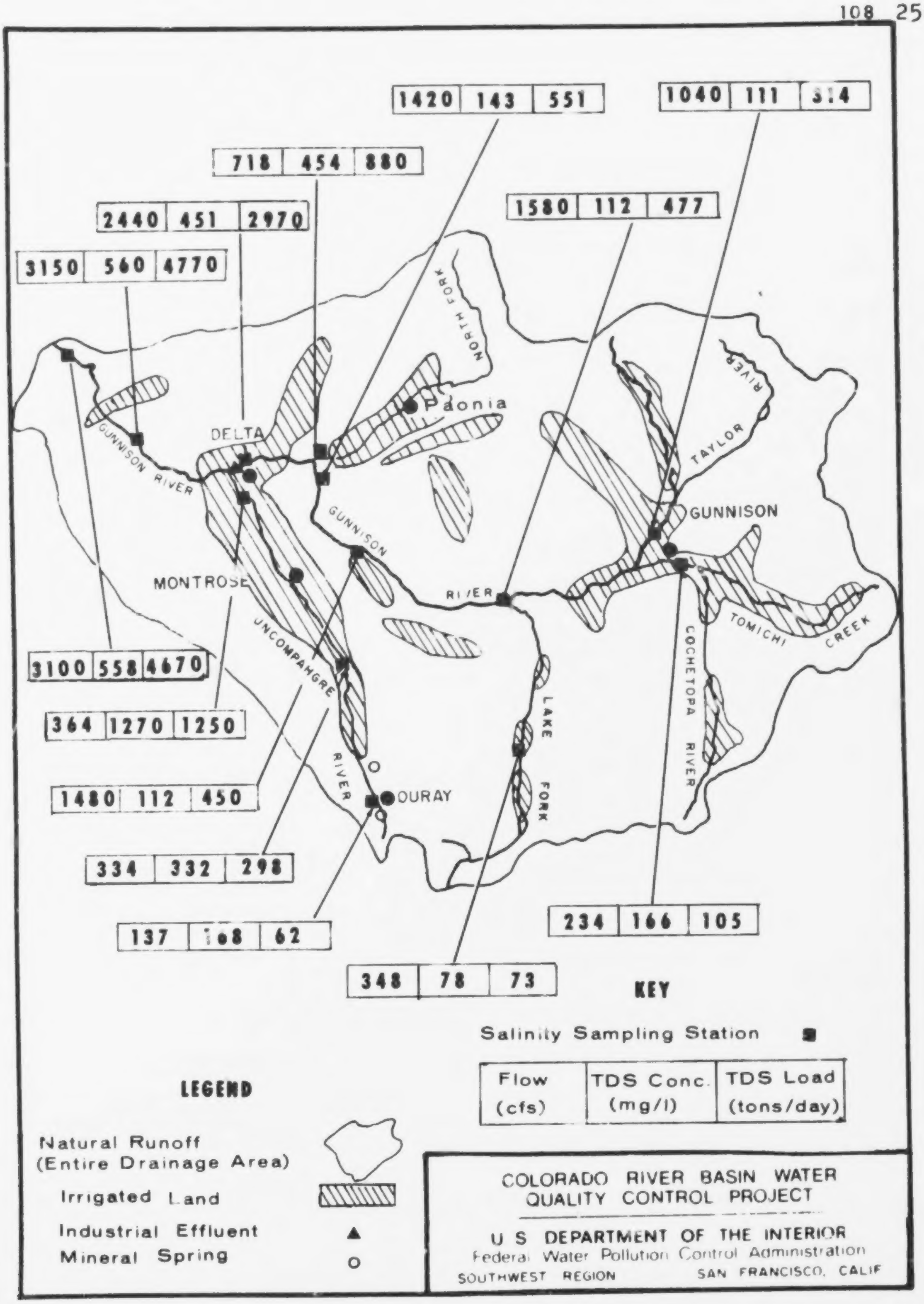
1420 143 551
1040 111 314
718 454 880
1580 112 477
2440 451 2970
3150 560 4770
NORTH FORK
Paonia
TAYLOR RIVER
DELTA
GUNNISON RIVER
GUNNISON
GUNNISON RIVER
MONTROSE
TOMICHI CREEK
COCHETOPA RIVER
LAKE FORK
UNCOMPAHGRE RIVER
OURAY
3100 558 4670
364 1270 1250
1480 112 450
334 332 298
137 168 62
234 166 105
348 78 73
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
Industrial Effluent ▲
Mineral Spring ○
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Figure 34 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Areas 18,19,20,&21 Upper Colorado River Basin, 1965-66

The Lake Fork drainage area contributed a mean flow of 348 cfs and a salt load of 73 tons per day during the period of the study. About one ton per day of this total salt load was contributed by drainage from abandoned mines located in the headwaters area of Lake Fork. Irrigation of 3,800 acres in the Lake Fork watershed contributed approximately one ton per day to the total salt burden. The remainder of the salt load resulted from natural runoff, and the low yield is indicative of the highly resistant character of the igneous and metamorphic rocks underlying the area. Closure of Blue Mesa Dam on the Gunnison River during the period of study precluded development of a salt budget for that reach of the stream. During summer runoff, the area yielded approximately 1,000 cfs and 300 tons of salt per day. This yield declined to 150 cfs and 30 tons per day just prior to closure of the dam in October 1965.

The Uncompahgre River drainage area, upstream of Ouray, Colorado, yielded a mean annual flow of 137 cfs and a salt load of 62 tons per day. Drainage from active and abandoned mines in the area above Ouray yielded approximately 9 cfs and 13 tons of salt per day. Much of the mine drainage is highly toxic and precludes aquatic life in many of the headwater streams.

Flow from Ouray Hot Spring is collected in Box Canyon and piped downstream to a swimming pool located below Ouray. Overflow from the pool is discharged into the Uncompahgre River and adds a salt load of approximately 4.5 tons per day to the stream. Other hot mineral springs located along the Uncompahgre River, about one mile above Ridgeway, add approximately 1 cfs and 7 tons of salt per day to the stream. Water budgets for the Uncompahgre River below Ouray and above the mouth of Dallas Creek showed flows varying from a loss of 29 cfs to a gain of 278 cfs. The large variation in flow is due to the seasonal nature of the runoff and the diversion of water for irrigation. The mean annual flow in the reach was 28 cfs and the mean salt load was 124 tons per day. Irrigation of 6,000 acres in the Uncompahgre River Valley consumed 7 cfs and added 74 tons of salt per day to the stream. The salt yield from irrigation which was calculated to average 4.5 tons per acre per year, was attributable to leaching of minerals from saline soils of the area. Runoff from soluble sedimentary outcrops within the Region contributed approximately 50 tons of salt per day. Losses in salt load, within the reach of the Uncompahgre River between Ridgeway and Colona, indicated the possibility of salt storage in irrigated lands.

Water and salt budgets for the Lower Gunnison Valley in the vicinity of Montrose and Delta are highly complex. A detailed discussion of sources and changes in mineral quality within this reach is available in an open file report at the Project Office in Denver, Colorado. Irrigation of 164,000 acres in Gunnison Valley, most of which is underlain by gypsiferous Mancos shale, yielded a salt load of approximately 3,000 tons per day or an average 6.7 tons per acre per year. This high yield results from application of irrigation water to soils derived from the Mancos shale.

During the year of study, the Gunnison River Basin yielded a mean annual flow of 3,100 cfs and a mean salt load of 4,670 tons per day. The 3,000 tons per day from irrigation in the Lower Gunnison River Basin represents 64 percent of the total salt load additions to the area.

An additional salt load of 100 tons per day was contributed by irrigation throughout the remainder of the Gunnison Basin.

The chemical composition of the upper reaches of the Gunnison River, Tomichi Creek, and Lake Fork was typical of headwater streams derived from highly resistant rock formations. In the lower reach of the Gunnison River, there was a significant change in chemical composition which was caused by runoff from the North Fork of the Gunnison River and irrigation in the vicinity of Delta. Solution of saline minerals in the Mancos shale in this area caused calcium and sulfate to predominate.

Chemical composition of the upper reaches of the Uncompahgre River was unusual for headwater streams in that calcium and sulfate predominated. The high concentration of these chemicals was due primarily to mine drainage and natural oxidation of sulfide minerals in the Red Mountain Creek drainage area. Calcium and sulfate were predominate throughout the lower reaches of the Uncompahgre and Gunnison Rivers due to irrigation return flows and runoff from the widespread gypsiferous Mancos shale in the area.

The salt budget for Study Areas 18, 19, 20, and 21 is shown in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Municipal	36[1/]	0.8
Irrigation	3100	66.4
Mine drainage	14	0.3
Runoff and Springs	1520	32.5
Total	4670	

[1/] Includes ungaged infiltration to the Delta sewage collection system.

Study Area 22 (Upper Main Stem)

Description. Study Area 22 consists of the Colorado River watershed between Loma, Colorado, and the mouth of the Dolores River (Figure 35). It covers an area of approximately 1,190 square miles in northeastern Grand County, Utah, and northwestern Mesa County, Colorado. Tributaries within the area include the Little Dolores River, Westwater Creek, Bitter Creek, and Cottonwood Wash, all of which yield insignificant runoff.

The area is characteristic of the Colorado Plateau with steep-walled buttes rising high above the valleys occupied by intermittent streams. The tops of the buttes are forested while the valleys are generally barren. Elevations in the area range from 4,000 to 9,500 feet. Annual precipitation ranges from slightly less than 8 inches, along the river, to more than 20 inches at high elevations. The total area yields insignificant runoff.

Findings. There were no significant salt load additions by tributaries during the study period, and there were no consumptive losses within the reach other than evapotranspiration by phreatophytes in the valleys. During the study period, flow within this area decreased by 70 cfs and the salt load decreased by 60 tons per day. The observed changes in flow and salt loading are well within the limits of accuracy of stream measurement and sampling analysis. Small decreases in flow; however, may have occurred due to evapotranspiration. Some precipitation of minerals may also have occurred within the Colorado River reach in Study Area 22.

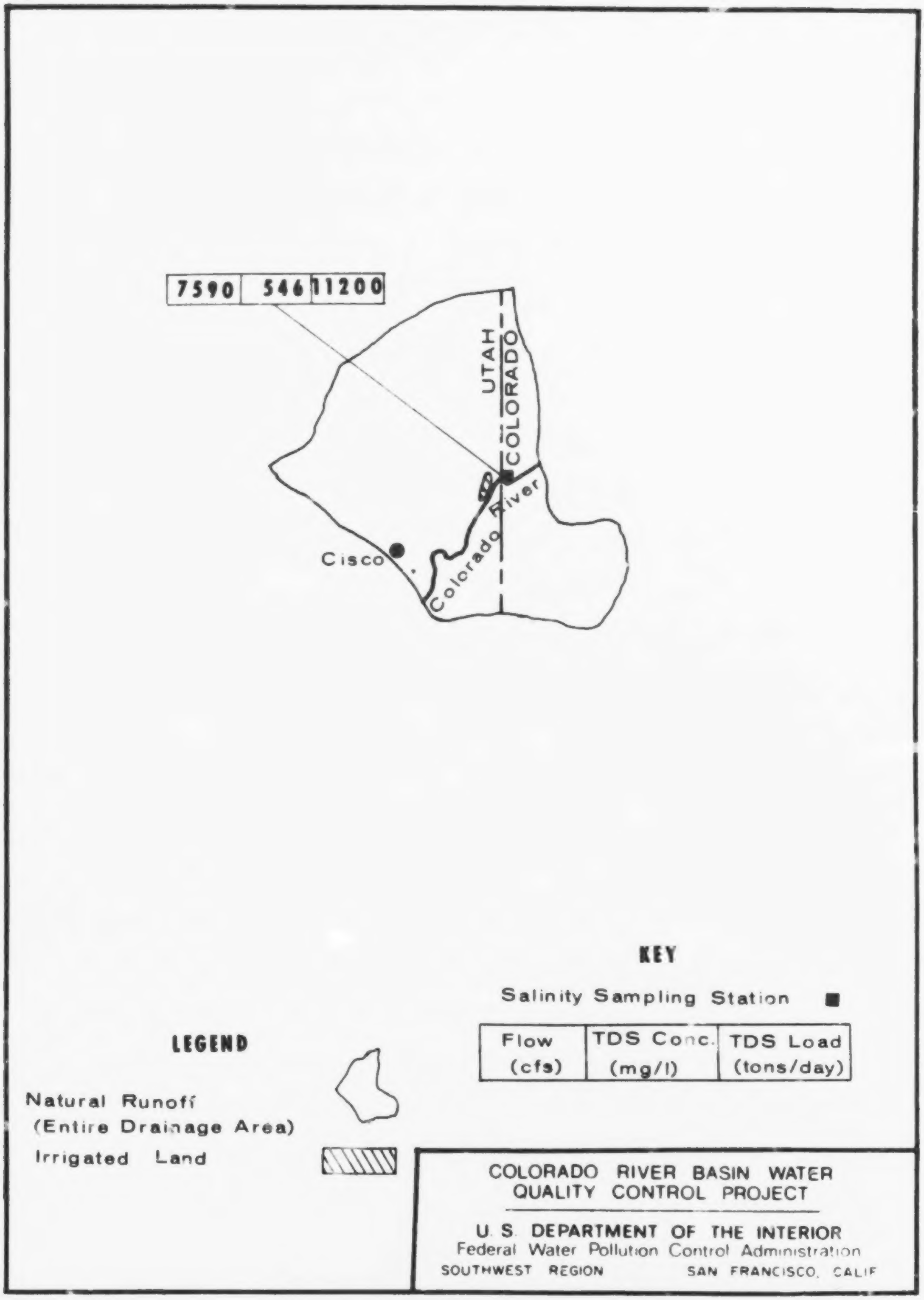
7590
546
11200
UTAH
COLORADO
Colorado River
Cisco
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
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Figure 35 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 22, Upper Colorado River Basin, 1965–66

Study Area 23 (Upper Main Stem)

Description. Study Area 23 includes the entire drainage area of the Dolores and San Miguel Rivers (Figure 36). It covers 4,536 square miles in Montezuma, Dolores, San Miguel, Montrose, and Mesa Counties, Colorado, and in Grand and San Juan Counties, Utah. There are no communities of significance from the standpoint of effects on water quality. Active and inactive mines and mills within the area have profound effects on water quality. Elevations of the area range from 4,200 feet to more than 14,000 feet. The Dolores River and its major tributary, the San Miguel River, head in the alpine topography of the San Juan Mountains, in a region of high precipitation and resistant rocks. Most of the streamflow comes from these areas which comprise less than 10 percent of the study area. Downstream areas yield less runoff, having higher concentrations of TDS.

Findings. The highly resistant rocks upstream of Dolores yield large volumes of high-quality water. During the study period, the Dolores River at Dolores yielded a mean annual discharge of 580 cfs, and a mean salt load of 215 tons per day. Approximately 6 tons per day of this load were attributable to drainage from three mines in the Rico area. This drainage also contains high concentrations of heavy metals which limits aquatic life in the Dolores River. Stoner Creek discharged water with TDS concentrations of from 70 to 150 mg/l and the West Fork of the Dolores River had concentrations ranging from 100 to 350 mg/l. Paradise Hot Springs, located on the West Fork of the Dolores River, discharged water with a TDS concentration of 5,500 mg/l. This salt spring contributed a salt load of 1.7 tons per day and partially accounts for the higher

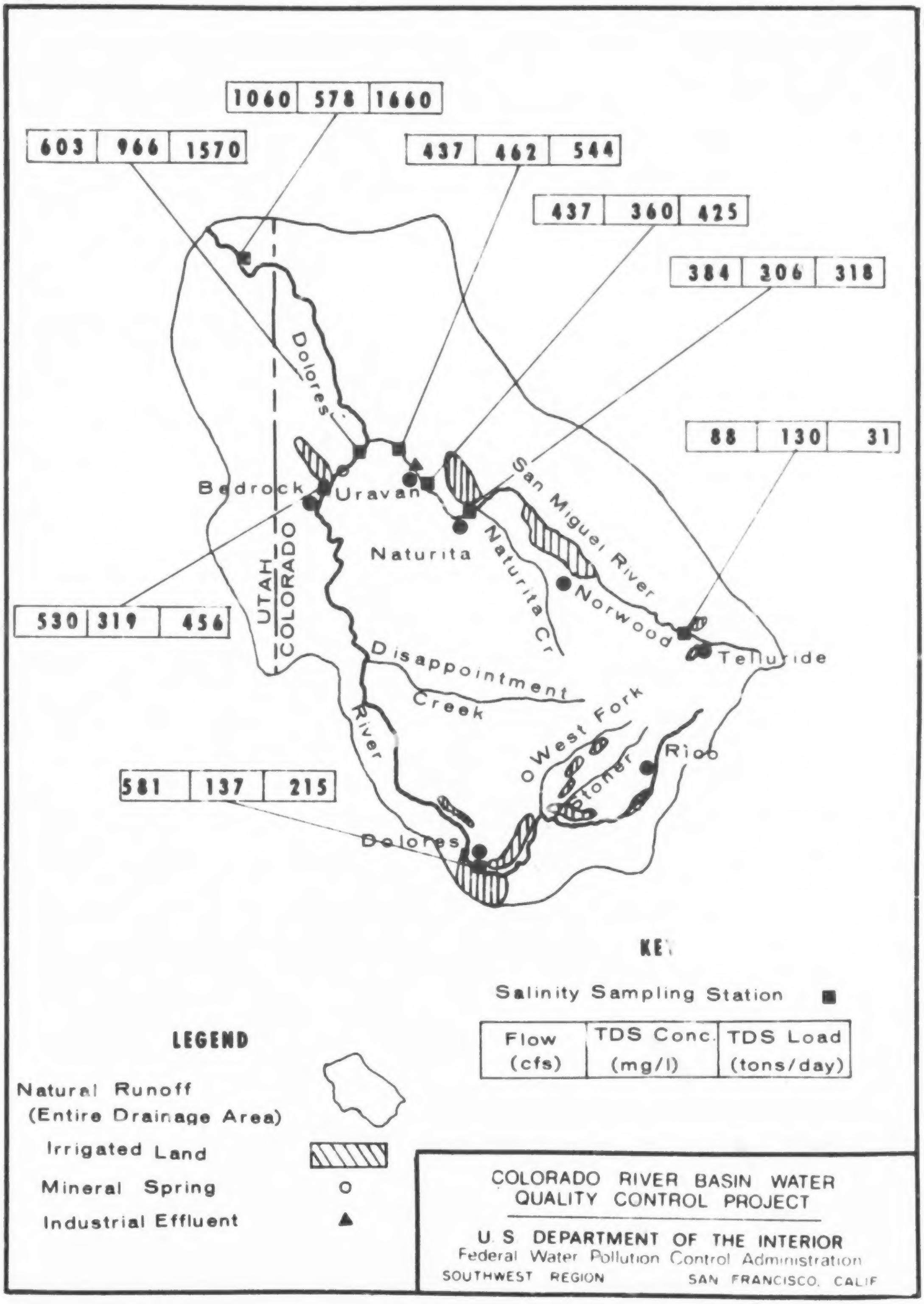
1060 | 578 | 1660
603 | 966 | 1570
437 | 462 | 544
437 | 360 | 425
384 | 206 | 318
88 | 130 | 31
530 | 319 | 456
581 | 137 | 215
Dolores
Bedrock
Uravan
Naturita
Naturita Cr
San Miguel River
Norwood
Telluride
UTAH
COLORADO
Disappointment Creek
River
West Fork
Stoner
Rico
Dolores
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
Mineral Spring ○
Industrial Effluent ▲
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Figure 36 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 23, Upper Colorado River Basin, 1965–66

mineral concentrations in West Fork. A small amount of irrigation may also contribute some salt to the West Fork. Much of the flow in the Dolores River is diverted into the McElmo Creek Basin. This diversion of high-quality water deprives the Dolores River system of dilution water in the downstream reaches.

Disappointment Creek, which flows over Mancos shale throughout its entire length, discharged salt loads of from 3 to 142 tons per day to the Dolores River. The runoff of Disappointment Creek was highly mineralized throughout the year.

The Dolores River at Bedrock discharges a mean annual flow of 530 cfs and a mean salt load of 456 tons per day. This reflects a decrease of 50 cfs and an increase of 240 tons per day over the stream reach between Dolores and Bedrock. The decrease in flow resulted from the diversion of water to the McElmo Creek Basin. This diversion also carried a small amount of salt out of the Dolores River Basin.

In the reach of the Dolores River between Bedrock and the mouth of the San Miguel River, water quality is severely degraded by solution of minerals in Paradox Valley. The mean salt load addition, due to solution of minerals from the Paradox Valley salt anticline, was calculated to be 688 tons per day. A detailed discussion of the geohydrologic conditions which are responsible for this major salt load is available in an open file report at the Project Office in Denver, Colorado.

The San Miguel River below Telluride had a mean flow of 88 cfs and a mean salt load of 31 tons per day, reflecting the high quality of runoff from the San Juan Mountains. This salt load included approximately 4 tons per day from several active and abandoned mines in the headwaters area. The Idarado Mining Corporation mill above Telluride adds small amounts of salt through seepage from a tailings pond.

In the reach of the San Miguel River between Telluride and Naturita, flow increased by 296 cfs and the salt load increased by 287 tons per day. The South Fork of the San Miguel River contributed 30 to 150 tons of salt per day of which approximately 10 tons per day resulted from drainage from mines in the headwaters area. Naturita Creek added a salt load of approximately 70 tons per day of which 46 tons per day were attributable to irrigation of approximately 6,000 acres in the Norwood area. The salt yield attributable to irrigation averaged approximately 2.8 tons per acre per year. The remainder of the salt load increase was due to natural runoff from formations containing soluble minerals.

The San Miguel River above Uravan had a mean annual flow of 437 cfs and a mean salt load of 425 tons per day. This represents an increase of 53 cfs and 107 tons of salt per day in the reach between Naturita and Uravan which was due to diffuse groundwater inflow and overland runoff.

At the station below Uravan, there was a mean annual salt load of 544 tons of salt per day, a gain of 119 tons per day in the Uravan reach. Effluent from the Union Carbide Uranium Mill at Uravan contributed approximately 24 tons of salt per day. An unknown amount of the increase within the Uravan reach was contributed by seepage from the industrial waste holding ponds adjacent to the San Miguel River bed at the Union Carbide mill.

The mean flow and salt load in the Dolores River near Cisco was 1,060 cfs and 1,660 tons per day, respectively. This represents an increase of 20 cfs and a decrease of 454 tons per day within the reach between the mouth of the San Miguel River and the station at Cisco. The magnitude of the decrease in salt load approximated the magnitude of an unexplained increase in the Dolores River between Bedrock and the mouth of the San Miguel River. This disparity cannot be further refined in the absence of improved flow measurements on the Dolores River above the mouth of the San Miguel. The Dolores at this point is a steep, boulder-strewn canyon in which accurate flow measurement is virtually impossible.

Sinbad Valley, a small collapsed anticline similar in nature to Paradox Valley salt anticline, is drained by Salt Creek. The TDS concentrations in Salt Creek during the year of study ranged from 34,000 mg/l to 49,300 mg/l, although the salt load contributed to the Dolores was only approximately 9 tons per day. Additional salt loads may enter the Dolores River from the Salt Wash area as underflow from the alluvium in Salt Wash Canyon.

Chemical composition of the headwaters of the Dolores River was typical of headwater streams with calcium bicarbonate water of low TDS concentrations. At Bedrock, the chemical composition of the Dolores River was altered significantly by solution of minerals in Gypsum Valley and the inflow of Disappointment Creek. Ionic composition of the Dolores River, above the mouth of the San Miguel River, was altered drastically by the addition of sodium chloride and calcium sulfate from the Paradox formation.

The chemical composition of the headwaters of the San Miguel River was very similar to that of the Uncompahgre River. Both streams head in the San Juan Mountains and have calcium-sulfate type waters, reflecting the oxidation of sulfides from natural sources and from active and abandoned mines. Downstream stations on the San Miguel show essentially no change in the proportion of the mineral constituents, but do reflect substantial increases in all constituents. The Dolores River near Cisco showed an increase in the proportion of sulfate, and a decrease in the proportions of sodium and chloride, as a result of minerals contributed by the San Miguel River.

The salt budget for Study Area 23 is shown in the Following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load*
Irrigation	46	4.8
Industrial Effluent and Seepage from Ponds	119	12.4
Springs and Salt Seeps	695	72.5
Mine Drainage	20	2.2
Runoff	780	8.1
Total	1660	

Study Area 24 (Upper Main Stem)

Description. Study Area 24 encompasses the Colorado River watershed below the mouth of the Dolores River and above the mouth of the Green River (Figure 37). It covers an area of 2,504 square miles in Grand and San Juan Counties, Utah. The area includes the community of Moab, Utah, which had a population of 4,682 in 1960. Onion Creek, Castle Creek, Salt Wash, Mill Creek, Hatch Wash, and Indian Creek contributed insignificant flow during the study period. The effluent from the Atlas Mineral Coporation uranium mill at Moab was the only significant inflow in the area. This mill added a mean salt load of 36 tons per day to the Colorado River.

*See corrected percentages, Page 724.

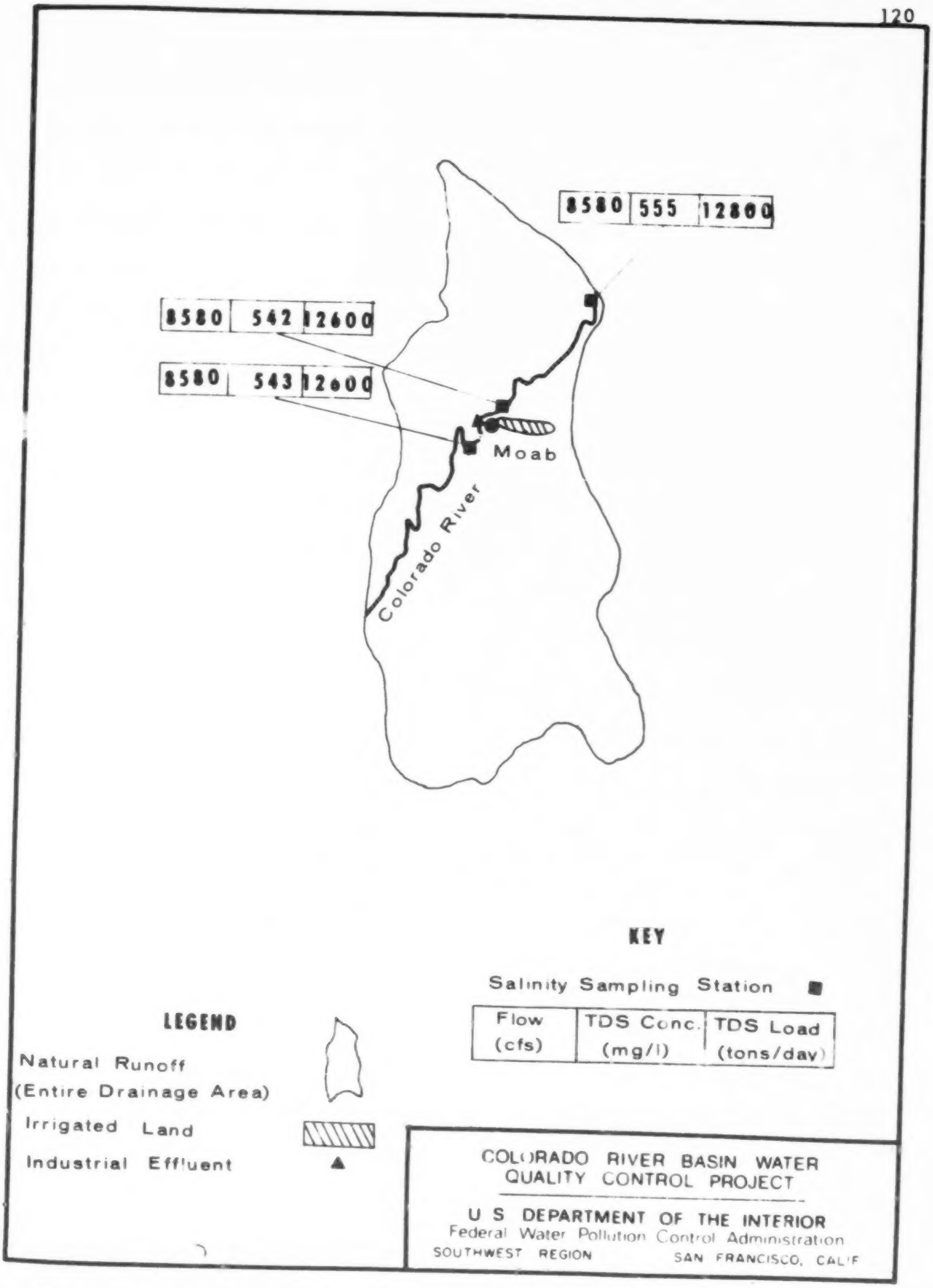
8580 | 555 | 12800
8580 | 542 | 12600
8580 | 543 | 12600
Moab
Colorado River
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Industrial Effluent ▲
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Figure 37 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 24, Upper Colorado River Basin, 1965–66

Study Area 25 (San Juan Subbasin)

Description. Area 25 includes the entire Dirty Devil River drainage area, which covers approximately 4,300 square miles in Wayne, Garfield, Sevier, and Emery Counties of Utah. Settlements in the area and their 1960 populations include Loa (359), Bicknell (366), Torrey (128), and Hanksville (80). The Dirty Devil River is formed at Hanksville by the junction of the Fremont River and Muddy Creek (Figure 38).

The topography consists of high block plateaus, which are partly lava capped, and young to mature canyoned plateaus with high relief. With the exception of volcanic rocks in the headwaters of the Fremont River, virtually the entire sedimentary section crossed by the Dirty Devil River and its upstream tributaries is easily eroded and yields poor quality ground-water. These conditions result in poor quality runoff downstream of Bicknell. There are only a few perennial streams within the area.

Findings. The Fremont River above the community of Fremont discharged approximately 26 cfs and a salt load of 10 tons per day during the study period. This high-quality water is derived from headwaters underlain by relatively insoluble lava flows. An increase in flow of 28 cfs and a salt load pickup of 47 tons per day was observed between the Fremont station and the station upstream of Torrey. Approximately 14 cfs and 8 tons of salt per day of this change was attributable to inflow from a spring at Loa Fish Hatchery. A salt load of approximately 20 tons per day was contributed by irrigation of 18,000 acres upstream of Torrey. The salt yield from irrigation averaged approximately 0.4 tons per acre per year.

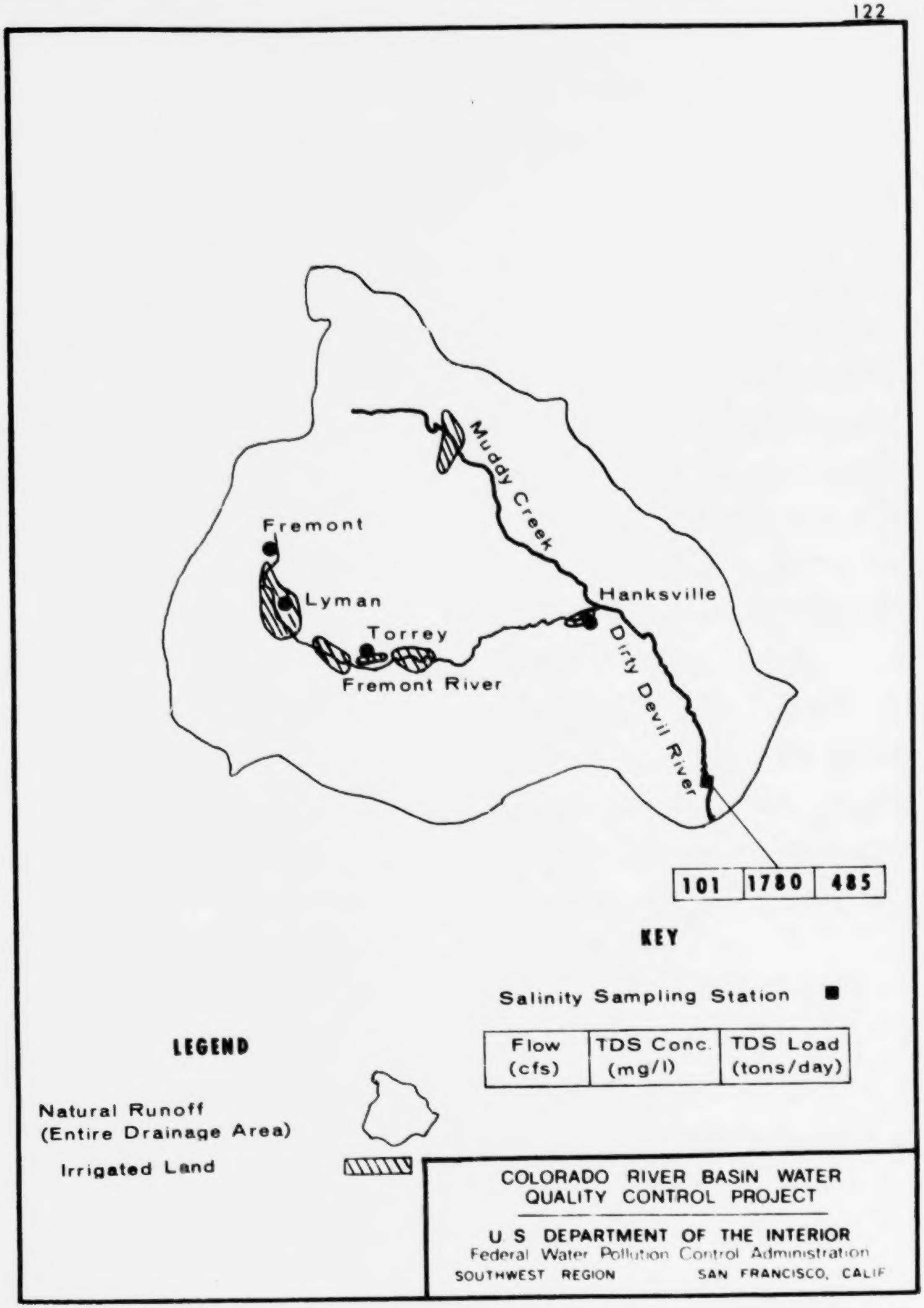
Muddy Creek
Fremont
Lyman
Torrey
Hanksville
Fremont River
Dirty Devil River
101
1780
485
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U S DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

Figure 38 Flow and Quality at Key Sampling Stations and Location of Principal Salinity Sources in Study Area 25. Upper Colorado River Basin. 1965–66

The reach of the Fremont River between Torrey and Caineville received inflow of 9 cfs and a salt load of 33 tons per day during the study period. Virtually all of this inflow was due to natural runoff over formations which become increasingly saline in the lower reaches of the drainage area. In the reach between Caineville and the mouth of Hanksville, the Fremont River experienced a mean annual depletion of 6 cfs, but a salt load gain of 32 tons per day. The small amount of irrigation within the drainage area caused a salt load increase of about 16 tons per day. The leaching of soluble salts by runoff in the immediate drainage area also added about 16 tons per day to the system.

The waters of Muddy Creek at its mouth were highly saline during the entire study period. Concentrations of TDS ranged from 3,600 mg/l to 5,400 mg/l. Most of this salt was due to natural leaching from the Mancos shale in the Castle Valley area upstream of the San Rafael swell. Approximately 60 tons per day of the total salt load is attributable to irrigation of 7,000 acres upstream of the San Rafael swell.

The Dirty Devil River, from its origin at the junction of the Muddy and Fremont Rivers to its mouth at Lake Powell, flows through remote, uninhabited areas. The area contributed almost no runoff, but some salts are added to the system by leaching from the streambed and banks. The Dirty Devil River contributed 101 cfs and a salt load of 485 tons per day.

Waters of the Dirty Devil River were of calcium-sulfate type, which reflected leaching of gypsum from the Mancos shale outcrop area along the Fremont River.

The salt budget for Study Area 25 is given in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Irrigation	96	19.8
Springs	8	1.6
Runoff	381	78.6
Total	485	

Study Area 26 (San Juan Subbasin)

Description. Area 26 consists of the Colorado River drainage area between the mouth of the Green River and Lees Ferry, Arizona, excluding the drainage area of the Dirty Devil and San Juan Rivers (Figure 39). This extremely remote area receives little inflow, and yields almost no runoff, except from the highlands along the western boundary of the area. Two streams, the Escalante and Paria Rivers, discharge to the Colorado River within this reach. The Escalante River heads on the Great Basin Divide west of the town of Escalante, Utah, where formations are relatively resistent to weathering. The formations which make up the drainage area of the Paria River are easily eroded, as is evidenced by the bizarre structure in Bryce Canyon.

Findings. Runoff from the area during the study period was practically nil. Total dissolved solids concentrations in the Escalante River were usually on the order of 300 to 400 mg/l. Concentrations of TDS in the Paria River usually exceeded 1,000 mg/l. The salt load from the entire drainage area had virtually no effect on the Colorado River during the period of study.

Study Areas 27 and 28 (San Juan Subbasin)

Description of Area 27. This study area includes the San Juan River watershed upstream of Shiprock, New Mexico, excluding the Animas and

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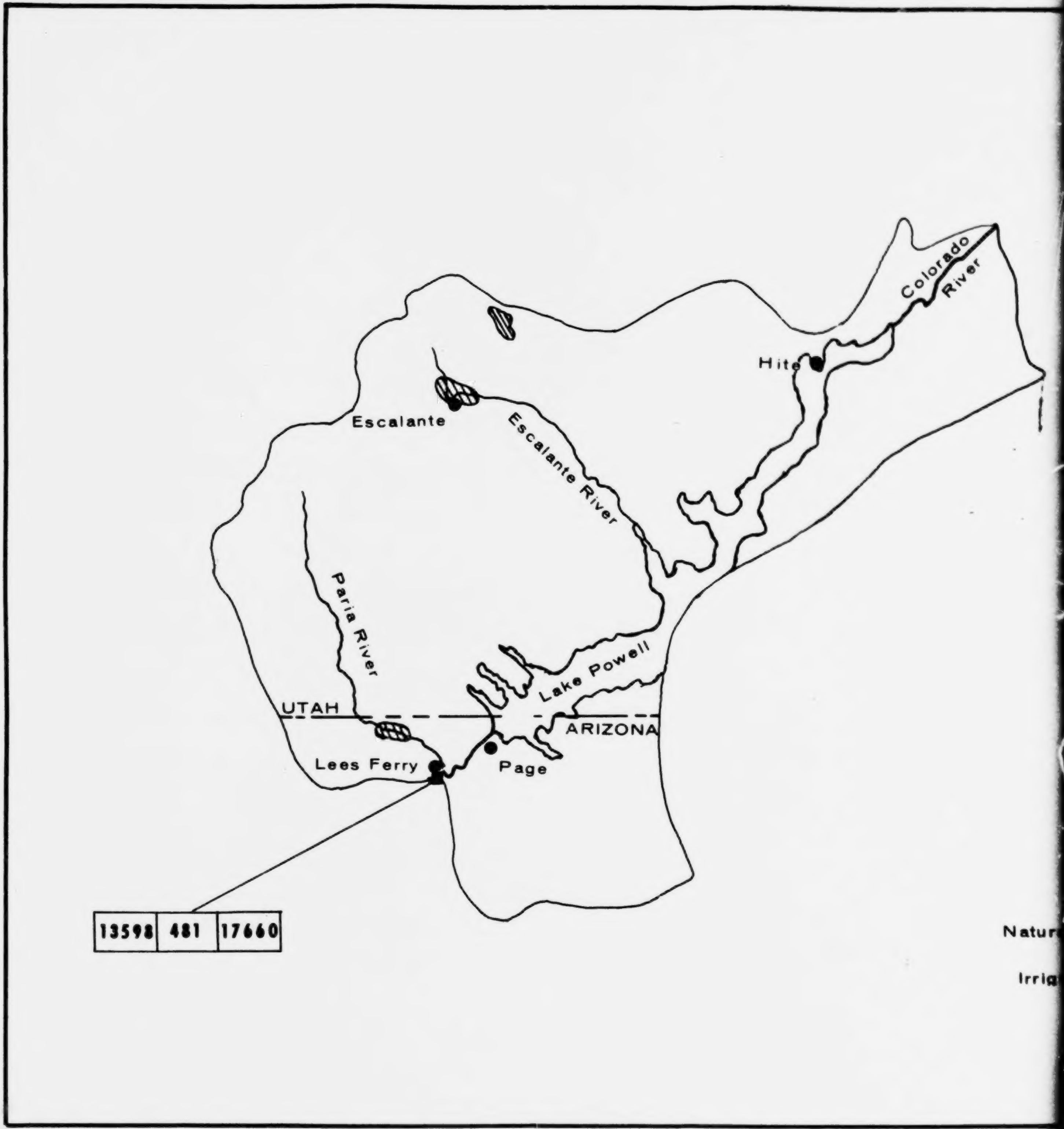
Colorado River
Hite
Escalante
Escalante River
Paria River
Lake Powell
UTAH
ARIZONA
Lees Ferry
Page
13598
481
17660
Natur
Irrig

Figure 39 Flow and Quality at Key Sampling Stations and Location
in Study Area 26. Upper Colorado River Basin. 19

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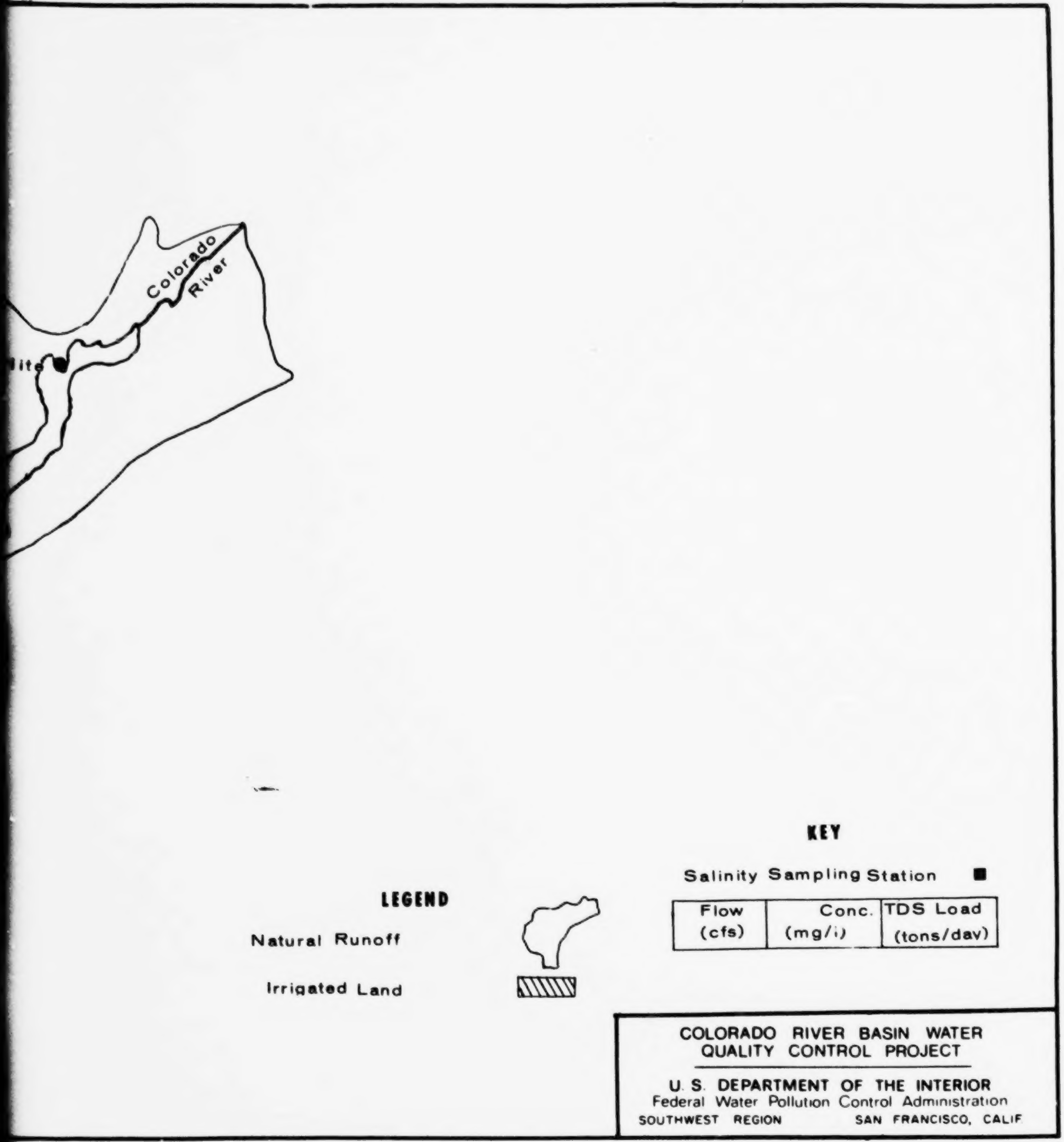
Colorado
River
LEGEND
Natural Runoff
Irrigated Land ▨
KEY
Salinity Sampling Station ■
Flow (cfs)
Conc. (mg/l)
TDS Load (tons/day)
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U. S. DEPARTMENT OF THE INTERIOR
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SOUTHWEST REGION
SAN FRANCISCO, CALIF

ing Stations and Location of Principal Salinity Sources
r Colorado River Basin, 1965–66

La Plata drainage areas (Figure 40). The area encompasses 11,484 square miles in Hinsdale, Archuleta, Mineral, and La Plata Counties of Colorado; and Rio Arriba, Sandoval, McKinley, and San Juan Counties in New Mexico. Principal communities in the area and their 1960 populations include Pagosa Springs, Colorado (1,374); and Farmington, New Mexico (23,786).

The San Juan River and its tributaries head on the Continental Divide in the glaciated Rocky Mountains. Below Pagosa Springs, the streams flow on flat-lying sediments of the Colorado plateau. Elevations range from approximately 4,950 feet at Shiprock to more than 13,000 feet in the headwaters areas. Precipitation varies from less than 8 inches in the lowlands to more than 20 inches in the headwaters areas, with virtually all the streamflow being derived from a small portion of the area.

Description of Area 28. This area consists of the Animas and La Plata River drainage basins, which cover 1,340 square miles in San Juan and La Plata Counties in Colorado; and San Juan County in New Mexico. Principal communities in the area and their 1960 populations include Durango (10,530) and Silverton (822) in Colorado; and Aztec (4,137) in New Mexico. A portion of the city of Farmington, New Mexico, also lies within the Animas drainage. Elevations range from 5,400 feet at Farmington to more than 13,000 feet in the headwaters areas. Precipitation varies from less than 8 inches to over 20 inches per year, with the bulk of the runoff coming from the high mountains in Colorado.

Findings (Areas 27 and 28). Because of the complex system of water interchanges between Areas 27 and 28, they are considered together in the discussion of findings.

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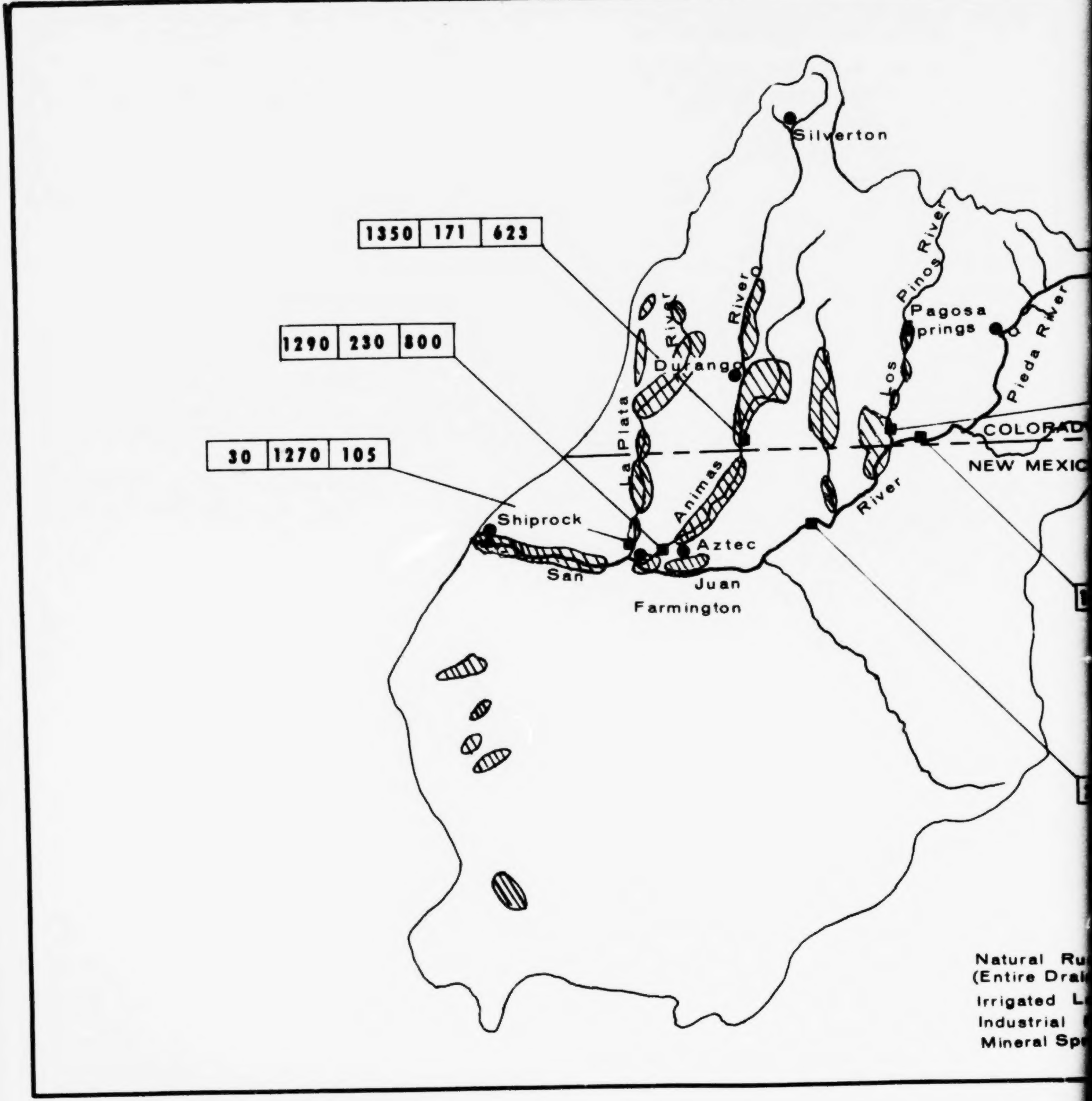
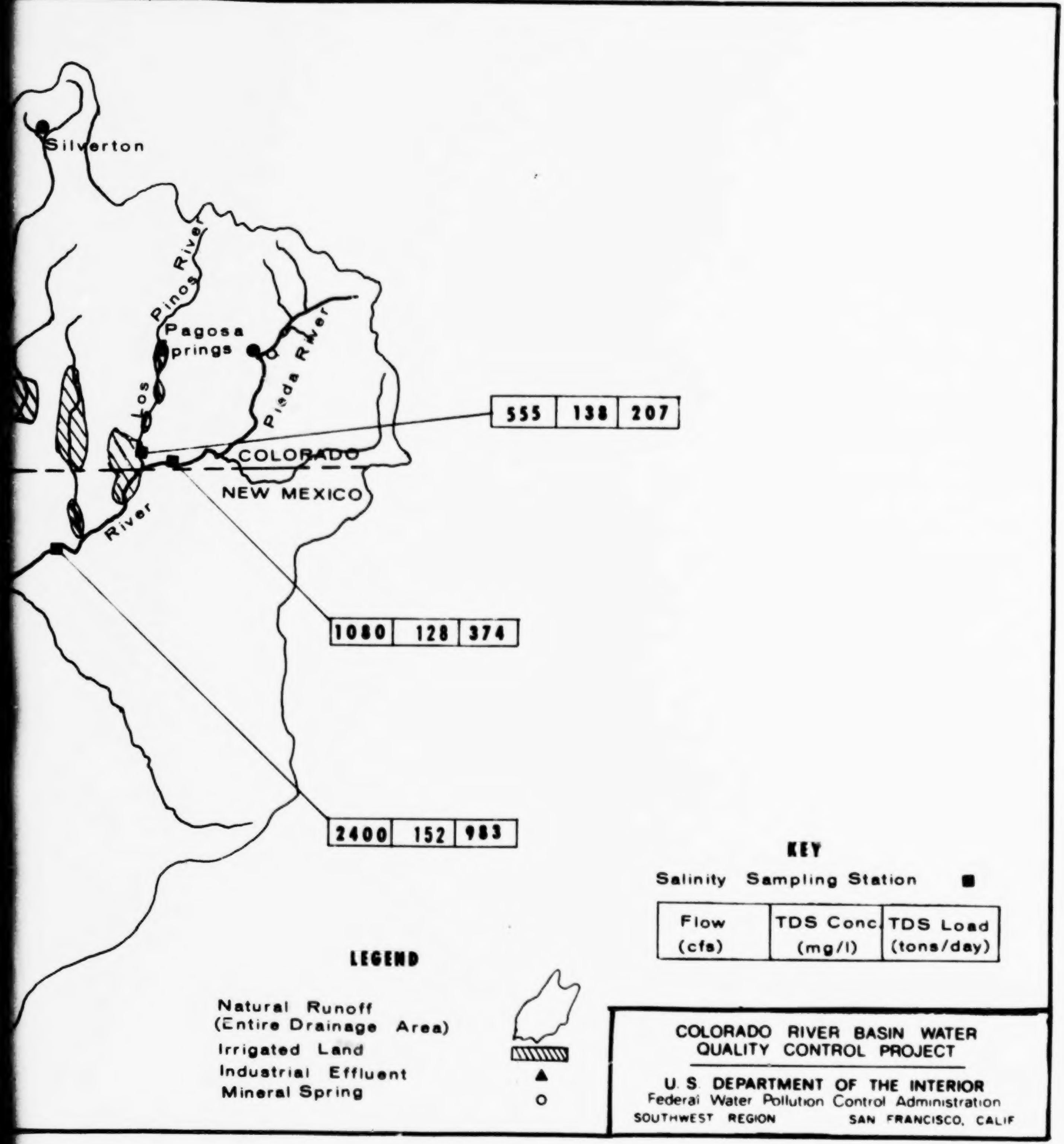

1350 171 623
1290 230 800
30 1270 105
Silverton
Durango
Pagosa
Springs
Los Pinos River
Piedra River
River
La Plata River
Animas River
River
COLORAD
NEW MEXIC
Shiprock
Aztec
San Juan
Farmington
Natural Ru
(Entire Drai
Irrigated L
Industrial
Mineral Sp

Figure 40 Flow and Quality at Key Sampling Stations and
in Study Areas 27 & 28, Upper Colo


Silverton
Pinos River
Los
Pagosa Springs
Piedra River
River
COLORADO
NEW MEXICO
555 | 138 | 207
1080 | 128 | 374
2400 | 152 | 983
KEY
Salinity Sampling Station ■
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
Industrial Effluent ▲
Mineral Spring ○
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

y Sampling Stations and Location of Principal Salinity Sources
ns 27 & 28, Upper Colorado River Basin, 1965-66

Irrigation of approximately 12,000 acres above Pagosa Springs contributed a salt load of 3 to 4 tons per day to the San Juan River. This low average yield of 0.01 ton per acre per year indicates the insoluble nature of the formations underlying the irrigated areas. Mineral springs in the Pagosa Springs area yielded 2.3 cfs and 20 tons of salt per day to the San Juan River.

In the San Juan River reach, between Pagosa Springs and Carracas, Colorado, the mean annual increase in flow was 540 cfs and the salt load increase was 260 tons per day. Approximately 100 tons per day of this increase was due to irrigation of lands underlain by Mancos shale and Tertiary sediments, which are rich in soluble minerals.

Because of the complex interrelations between diversions and returns within the watersheds of the Animas River between Durango and Cedar Hill, and the Los Pinos and Florida Rivers, a water and salt budget was prepared for this entire area. During the study period, the mean salt load from irrigation in the area was only 33 tons per day, or an average yield of approximately 0.2 tons per acre per year. In the Animas River reach between Cedar Hill and Farmington mean annual flow was depleted by 60 cfs but the salt load increased 177 tons per day. Irrigation of approximately 17,000 acres along this reach added 165 tons of salt per day, or an average 3.5 tons per acre per year. Runoff from the area contributed 33 cfs and 12 tons of salt per day to the river.

The Animas River headwaters above Howardsville are of fair quality, with TDS concentrations of less than 300 mg/l. Cement Creek was badly polluted with mine drainage and products of natural sulfide oxidation.

The pH of the stream was approximately 4 and TDS concentration was greater than 1,000 mg/l during the study period. Much of this pollution was attributable to drainage from an active mine at the old town of Gladstone; however, drainage from other abandoned mines and tunnels added to the problem. Mineral Creek is also polluted by mine drainage, although to a lesser degree. During the study period, pH ranged from 4.6 to 7.1 and TDS concentrations were less than 400 mg/l.

The Animas River reach, below Baker's Bridge and upstream of Durango, had a salt-load increase of approximately 100 tons per day. Pinkerton Hot Springs, at the Golden Horseshoe Ranch, accounted for approximately 5 tons of salt per day of this total. Other small springs, including Trimble Hot Springs, contributed unknown amounts of salt to the stream. The remainder of the salt load within the reach may result from mineralized inflow into the stream directly from alluvium along the river.

Almost the entire flow of the La Plata River is consumed during the irrigation season. The allocation of water between Colorado and New Mexico is defined by the La Plata River Treaty. The mean annual flow of the La Plata River at its mouth during the study period was 30 cfs, and the salt load contributed was 105 tons per day. Irrigation of 15,000 acres in Colorado contributed 56 tons of salt per day, or an average yield of 1.4 tons per acre per year. Irrigation of 5,000 acres in New Mexico contributed 4 tons of salt per day, or an average yield of 0.3 tons per acre per year. The difference in salt yields from these areas is largely due to the presence of Mancos shale in the Colorado areas, and the less soluble formations underlying the New Mexico area.

Seepage from the tailings ponds at the Vanadium Corporation of America uranium mill at Shiprock added approximately 11 tons of salt per day to the San Juan River. Bottom ash and fly ash removal systems at the Four Corners Powerplant near Shiprock contributed a salt load of approximately 35 tons per day. The increase in total dissolved solids concentrations in the San Juan River, due to blowdown from the cooling systems, consumptive use, and discharge of minerals dissolved from fly ash and bottom ash, was 54 mg/l.

Chemical composition of all headwater streams in the study area were generally typical, except that proportions of sulfate were slightly higher due to irrigation in the headwater areas. Sulfate became predominant below the inflow from the La Plata River reflecting the effects of irrigation of gypsum-rich soils in the Colorado-New Mexico Border areas.

The salt budget for Study Areas 27 and 28 is given in the following tabulation.

Source	TDS Load (tons/day)	Percent of Total Load
Mine Drainage	15	1.0
Irrigation	362	24.0
Mineral Springs	25	1.7
Runoff	1,037	69.5
Municipal Effluents	10	.7
Industrial Effluent	46	3.1
Total	1,495	

Study Area 29 (San Juan Subbasin)

Description. Area 29 comprises the San Juan River drainage between Shiprock, New Mexico, and the San Juan arm of Lake Powell. It covers approximately 11,500 square miles and includes portions of Montezuma and Dolores Counties in Colorado; San Juan County of Utah; San Juan

County in New Mexico; and Apache and Navajo Counties in Arizona. Communities within the area and their 1960 populations include Cortez (6,764), Colorado; Bluff (100), Blanding (2,200), and Mexican Hat (250), Utah. The area downstream of Mexican Hat, Utah, is virtually inaccessible. Tributaries to the San Juan River include Mancos River, McElmo Creek, Navajo Springs Creek, and Chinle Wash. Elevations range from 4,000 feet to approximately 7,500 feet. Precipitation varies from less than 6 inches per year in the lowlands to approximately 16 inches per year along the northern boundary of the study area (Figure 41).

Area 29 is located in the flat-lying sediments of the Colorado Plateau. Streams are deeply incised, throughout most of the area, but ground-water is at such great depth that there is virtually no base flow to streams in the canyon areas. A principal tributary, the Mancos River, flows across the Mancos shale, dissolving salts from the formation, and degrading the stream. Other than during infrequent thunder storms, the only significant runoff originates in the uplands along the northern limits of the study area.

Findings. Flow in the San Juan River reach between Shiprock, New Mexico and Mexican Hat, Utah, increased by 240 cfs and the salt load increased by 2,490 tons per day during the study period. Much of the inflow is attributable to diversion from the Dolores River and subsequent irrigation and drainage in the McElmo Creek Basin. Intermittent tributary inflow within the reach conveyed approximately 650 tons of salt per day to the San Juan River. A major portion of this salt load was contributed by irrigation return flows, including water which originated upstream of the USGS gage on the San Juan River near Shiprock. Thus, it was not possible

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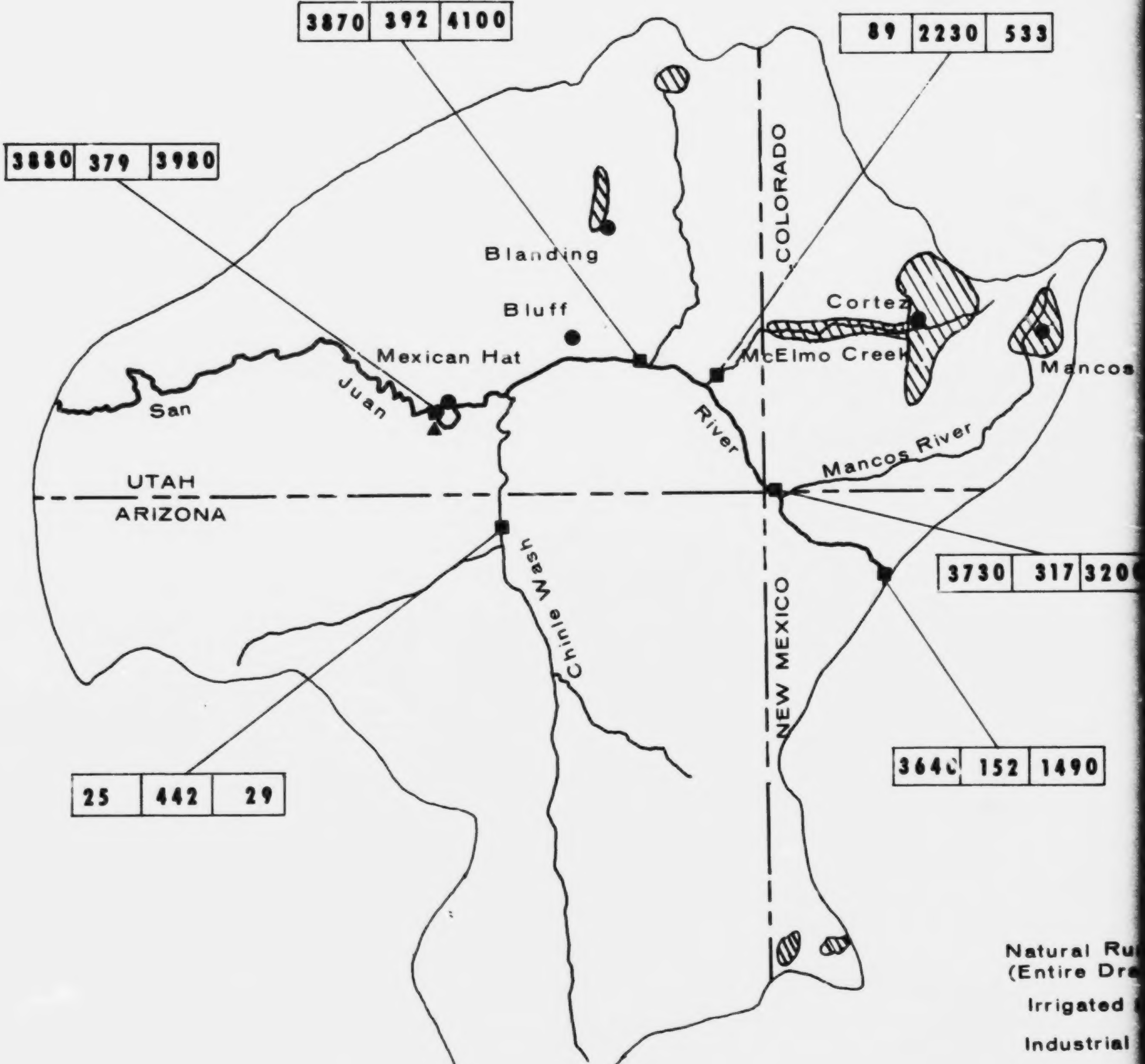
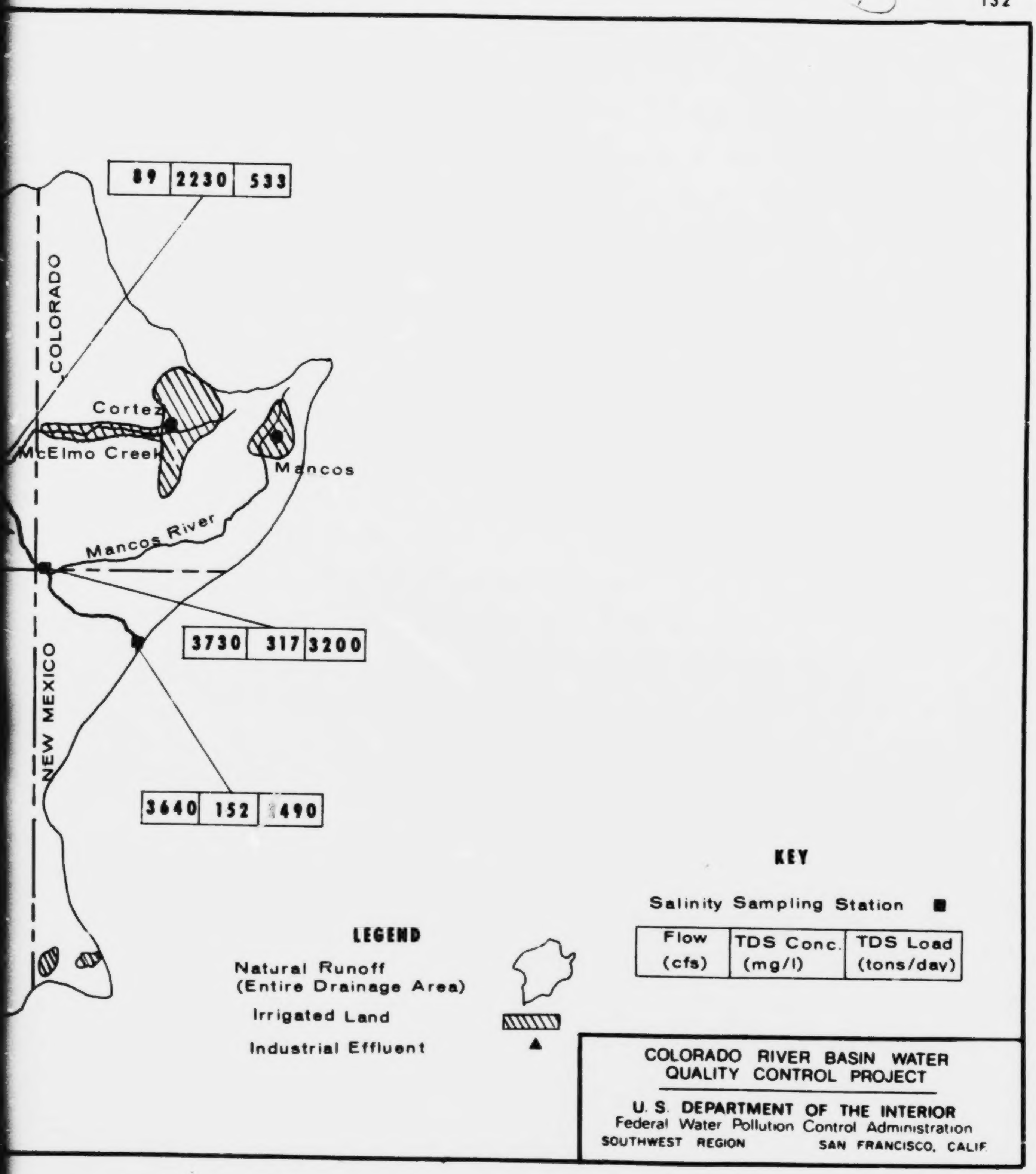

3870 | 392 | 4100
89 | 2230 | 533
3880 | 379 | 3980
COLORADO
Blanding
Bluff
Cortez
Mexican Hat
McElmo Creek
Mancos
San
Juan
River
Mancos River
UTAH
ARIZONA
Chinle Wash
NEW MEXICO
3730 | 317 | 320
3640 | 152 | 1490
25 | 442 | 29
Natural Ru
(Entire Dr
Irrigated
Industrial

Figure 41 Flow and Quality at Key Sampling Stations and Location of Prin
in Study Area 29, Upper Colorado River Basin, 1965–66


89 | 2230 | 533
COLORADO
NEW MEXICO
Cortez
McElmo Creek
Mancos
Mancos River
3730 | 317 | 3200
3640 | 152 | 1490
KEY
Salinity Sampling Station ■
Flow (cfs) | TDS Conc. (mg/l) | TDS Load (tons/day)
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
Industrial Effluent ▲
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF.

Stations and Location of Principal Salinity Sources
lorado River Basin, 1965–66

to develop an accurate salt and water budget for the area. Within this reach, the Mancos River upstream of the mouth of Navajo Creek contributed a salt load of approximately 100 tons per day. Navajo Springs Creek discharged approximately 80 tons of salt per day, virtually all of which was attributable to irrigation return flow in the Cortez-Towaoc area. TDS concentrations in the Mancos River varied from 280 mg/l during spring runoff to a high of 1,580 mg/l during the winter months. The concentrations in Navajo Springs Creek ranged from 1,790 mg/l to 6,480 mg/l.

McElmo Creek yielded a mean annual flow of 89 cfs and a salt load of 533 tons per day. Most of the flow in McElmo Creek is derived from irrigation in the Cortez area which is supplied by water diverted from the Dolores River. Chinle Wash contributed a mean flow of 25 cfs and a salt load of 29 tons per day. Flowing oil-test holes in the Four Corners area contributed an additional 5 tons of salt per day to the San Juan River system.

The proportions of mineral constituents remained essentially the same throughout the San Juan River reach in Area 29.

RESULTS OF FIELD INVESTIGATIONS - LOWER BASIN

A brief description of the Lower Colorado River Basin and the significant findings of the Project's field studies in the Lower Basin are presented in this section.

Description

For the purpose of this Appendix, the Lower Colorado River Basin consists of the drainage area directly tributary to the Colorado River from Lees Ferry near the Arizona-Utah state line to the Southerly International Boundary, excluding the upper reaches of the drainage areas of the Little Colorado and Gila Rivers. The tributary areas include lands in southwestern Utah, southern Nevada, southeastern California, and northern and western Arizona. Principal communities and their 1960 population are Las Vegas (170,000),[1/] Henderson (12,525), and Boulder City (4,058), Nevada; Kanab (1,645) and St. George (5,130), Utah; Kingman (4,525) and Yuma (23,974), Arizona; Needles (4,540) and Blythe (6,023), California. Numberous other small settlements and resort communities are located along the Colorado River between Davis Dam and Yuma.

Principal tributaries include Kanab Creek, Bright Angel Creek, Havasu Creek, the Virgin River, Muddy River, and the Bill Williams River. Throughout the Colorado Plateau portion of the Basin, the Colorado River flows through the Grand Canyon. The western and southern portions of the Basin are within the Basin and Range Province and are made up of a series of fault block and volcanic mountains separated by valleys filled to great depths with alluvium. The climate of the Basin varies widely from near Alpine conditions in the mountainous areas to true desert conditions in the lowlands along the lower reaches of the Colorado River. Annual precipitation ranges from less than 5 inches in the lower Colorado River area to more than 20 inches along the North Rim of the Grand Canyon. Only small portions of the Lower Colorado River Basin yield significant amounts of runoff.

Evaporation has a major effect on mineral quality in many areas of the Lower Colorado River Basin. Evaporation from lakes and reservoirs exceeds 6 feet annually in many areas. The concentrating effect of

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[1/] Includes metropolitan area outside city limits, but does not include visitor population.

transpiration by the large areas of phreatophyte growth along the streams also has a major influence on mineral quality of water.

Owing to low precipitation and high evaporation, the lowlands yield almost no runoff except during intense storms. Soluble minerals in the soil profile are leached out and discharged to streams during the infrequent runoff events.

Findings.

Lees Ferry to Hoover Dam. Flow and salt load in the reach of the Colorado River between Lees Ferry and Grand Canyon, Arizona, increased by 460 cfs and 2,310 tons per day during the study period. The flow and salt load contributed by various sources within this reach are given in the following tabulation (Figure 42).

Source	Flow (cfs)	TDS (mg/l)	Salt Load (tons/day)
Paria River at Lees Ferry	18.1	880	43
Little Colorado River at Cameron	209	780	439
Moenkopi Wash near Cameron	27.3	1,490	110
Blue Springs at mouth of Little Colorado River	222	2,500	1,500
Miscellaneous Springs	14.0		10
Total	490.4		2,102

Ionic composition within the reach was essentially constant throughout the study area (Figure 50).

Between the Grand Canyon station and Hoover Dam it is not possible to balance flow since there is no flow measurement on the Colorado River near its entrance to Lake Mead. If evaporation from the lake could be accurately quantified, ungaged flow into the lake could be calculated

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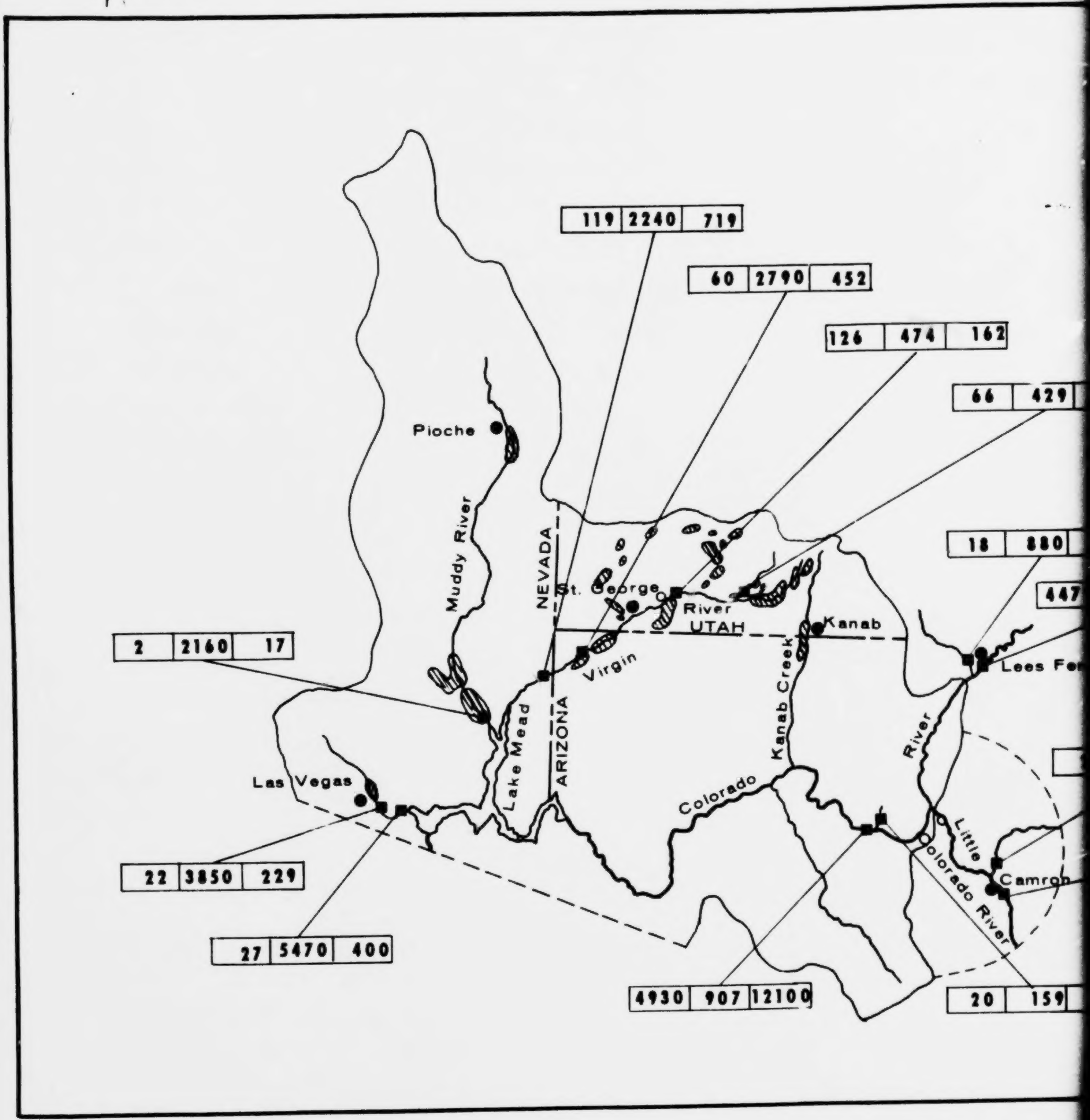
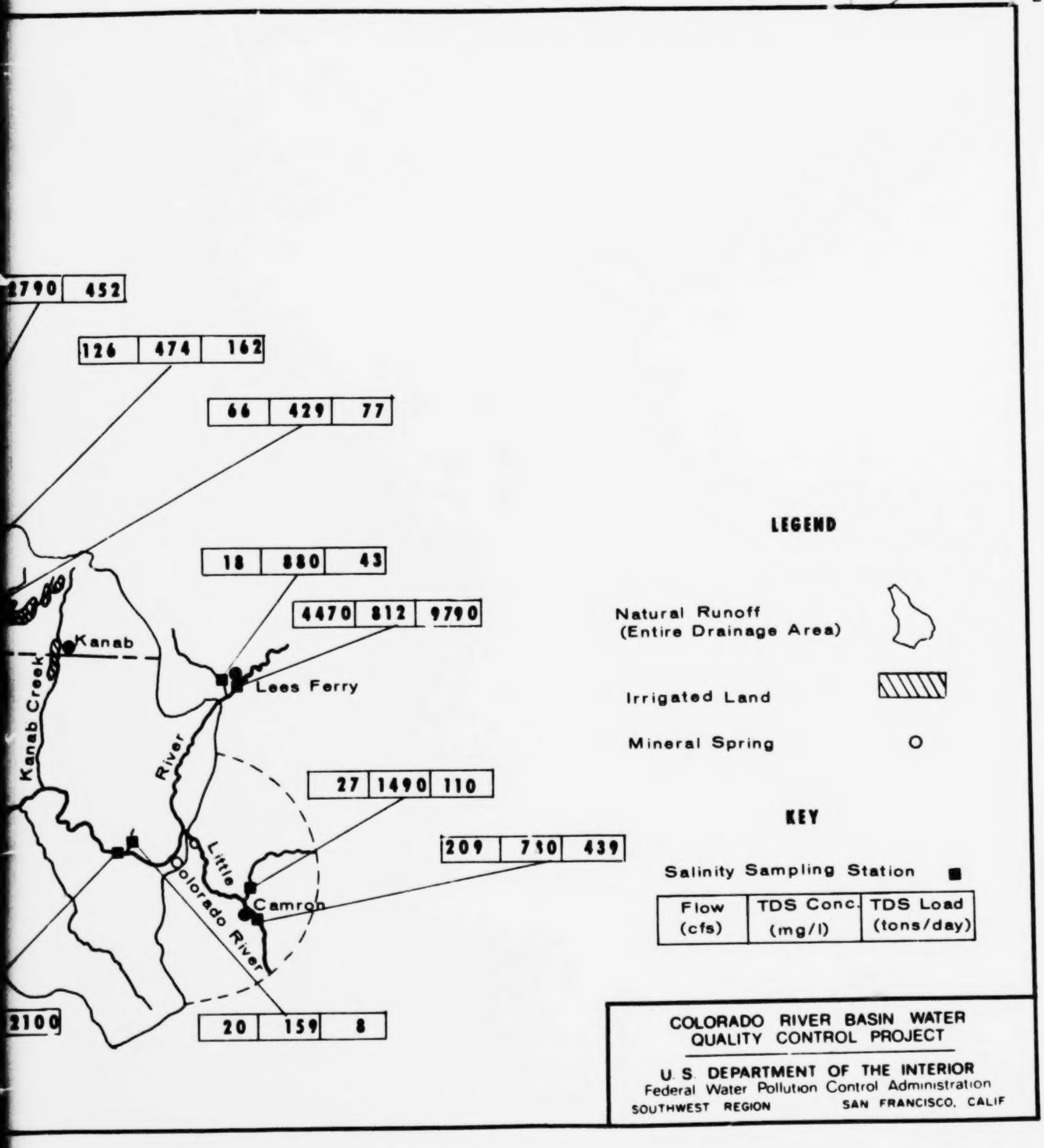

119 | 2240 | 719
60 | 2790 | 452
126 | 474 | 162
66 | 429
Pioche
Muddy River
NEVADA
St. George
River
UTAH
Kanab
18 | 880
447
Lees Fe
2 | 2160 | 17
Virgin
Lake Mead
ARIZONA
Kanab Creek
River
Las Vegas
Colorado
Little
Camron
Colorado River
22 | 3850 | 229
27 | 5470 | 400
4930 | 907 | 12100
20 | 159

Figure 42 Flow and Quality at Key Sampling Stations and Location of
Between Lees Ferry and Hoover Dam, Lower Colorado


2790 452
126 474 162
66 429 77
18 880 43
4470 812 9790
Kanab
Kanab Creek
Lees Ferry
River
27 1490 110
209 710 439
Little Colorado River
Camron
2100
20 159 8
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land
Mineral Spring
KEY
Salinity Sampling Station
Flow (cfs)
TDS Conc. (mg/l)
TDS Load (tons/day)
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

ling Stations and Location of Principal Salinity Sources
Hoover Dam, Lower Colorado River Basin, 1964

from evaporation losses and the sum of flows from the Grand Canyon gaging station and the intervening tributaries. Water and salt sources within the reach are shown in the following tabulation.

Source	Flow (cfs)	TDS (mg/l)	Salt Load (tons/day)
Bright Angel Creek	20	159	8
Tapeats Creek	80	120	26
Kanab Creek	12	1,180	38
Havasu Creek	70	352	66
Vulcan or Lava Falls Spring	6	750	10
Approx. 18 misc. springs	26		21
Virgin River at Riverside	60	2,790	452
Muddy River at mouth	2	3,160	17
Rogers Spring	2	3,200	17
Las Vegas Wash	27	5,470	400
Total	305		1,055

The headwaters of the North Fork of the Virgin River in Zion National Park yielded 66.3 cfs and 77 tons of salt per day. In the stream reach between Springdale and Virgin, Utah, flow increased by 60 cfs and salt load increased by 85 tons per day. These increases were attributable to ungaged inflow from the East Fork of the Virgin River and irrigation of small parcels of land in the Rockville, Springville, and Virgin areas.

In the reach of the Virgin River between Virgin, Utah, and Littlefield, Arizona, mean annual flow decreased by 7 cfs and salt load increased by 557 tons per day. Two major springs add salt and water to the Virgin

River within this reach. One of these, LaVerkin Springs, is located along both banks and in the channel of the Virgin River, immediately upstream of the trace of the Hurricane Fault, at LaVerkin, Utah. The discharge from this spring is of a sodium-sulfate-chloride composition and add 286 tons of salt per day to the system, as well as highly significant quantities of radioactive elements. The second spring, located at Littlefield, may not be an additional source since it is possible that it represents the reappearance of water which is lost from the Virgin River into the cavernous bedrock in Virgin Canyon between St. George and Littlefield. Irrigation of approximately 18,000 acres within the reach added a salt load of 112 tons of salt per day to the system, or an average salt yield of 2.3 tons per acre per year.

In the reach of the Virgin River between Littlefield, Arizona, and Riverside, Nevada, flow decreased by 59 cfs and the salt load decreased by 267 tons per day. These decreases in flow and load indicate that salt was stored in the irrigated areas during the study period.

Chemical composition of the Virgin River was not characteristic of headwaters streams (Figure 50). Calcium and bicarbonate were predominant, with concentrations of sodium and chloride nearly as high. Slight increases in the proportions of calcium and sulfide were observed at the sampling station at Virgin, Utah. At Littlefield the chemical composition of the Virgin River was significantly altered by the irrigation returns near St. George, Utah, and by the inflow from springs at LaVerkin and Littlefield. Sulfate and chloride concentrations increased sharply and all cations increased in approximately equal proportions. Additional consumptive use and irrigation return flows in the Littlefield and Mesquite areas caused increases in all mineral constituents in approximately equal proportions.

Essentially the entire flow of the Muddy River was utilized consumptively in the irrigation of approximately 9,000 acres. Another 10,000 acres in the area are irrigated by ground-water. Mean flow and salt load discharged at the most downstream station on the Muddy River was 2 cfs and 17 tons per day during the study period. The sampling station near the point of inflow to Lake Mead was situated such that considerable amounts of seepage from irrigation may not have been measured.

Chemical composition of the Muddy River at Glendale was predominantly calcium-sodium-sulfate reflecting the character of runoff from this area. Near the mouth of the Muddy River, sulfate and chloride became the predominant anions, and each of the principal cations increased.

Except during infrequent storms, flow in Las Vegas Wash is made up entirely of municipal and industrial effluent, seepage from industrial waste ponds, irrigation return flow, and outflow from an artificially recharged near-surface aquifer. During the period of study, mean annual flow and salt load measured at the USGS gage near Henderson, Nevada, was 22 cfs and 229 tons per day. The mean TDS concentration was 3,850 mg/l. At the mouth of Las Vegas Wash, mean flow was 27 cfs, mean salt load was 400 tons per day and the mean TDS concentration was 5,470 mg/l. Thus, an increase of 5 cfs and 171 tons per day occurred between the two stations. Since there were no surface inflows between these two stations, the increase in flow resulted in flow of ground-water which is not measured at the upstream gage. A natural bedrock sill below the gage apparently forces water moving in the aquifer upward into the stream increasing the

the surface flow at the mouth of the Wash. Discharge measurements at the two stations subsequent to the year of study indicate that the inflow between the two stations has increased to as much as 8 cfs.

Increases in individual mineral constituents between the two sampling stations on Las Vegas Wash were essentially proportional.

The salt budget for the reach of the Colorado River between Lees Ferry and Hoover Dam is given in the following tabulation.

Source	TDS Load (tons/day)	Percent of Average Load
Springs	1,990	58.0
Irrigation	112	3.3
Municipal	43	1.3
Runoff	1,282	37.4
Total	3,427	

Hoover Dam to Southerly International Boundary. The mean flows, TDS concentrations and salt loads at stations within this reach are shown in the following tabulation (Figure 43).

Location of Station on Colorado River	Flow (cfs)	TDS (mg/l)	TDS Load (tons/day)
Below Hoover Dam	11,430	721	21,860
Below Davis Dam	11,190	726	21,930
Below Parker Dam	9,290	723	18,130
Below Palo Verde weir	7,470	732	14,760
At Blythe-Ehrenberg Bridge	7,610	755	15,510
Below Cibola Valley	8,280	822	18,380

The causes of changes in flow and salt load between each of the stations are discussed briefly in the following sections. More detailed discussions of these changes are included in an open file report available at the Project Office in Denver, Colorado.

The increase in TDS concentration between Hoover Dam and Davis Dam is due to evapotranspiration by phreatophytes and inflow from saline

A

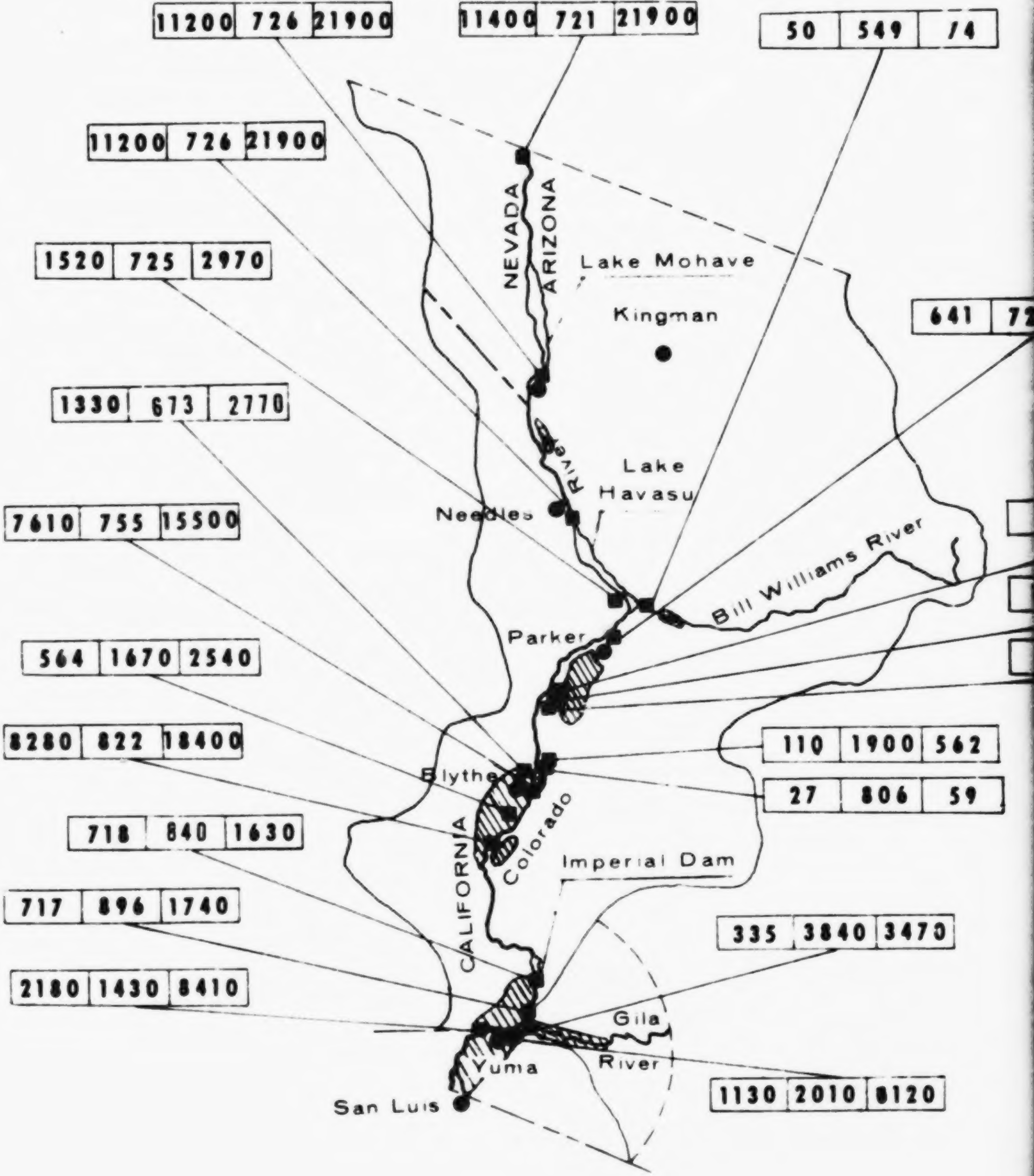
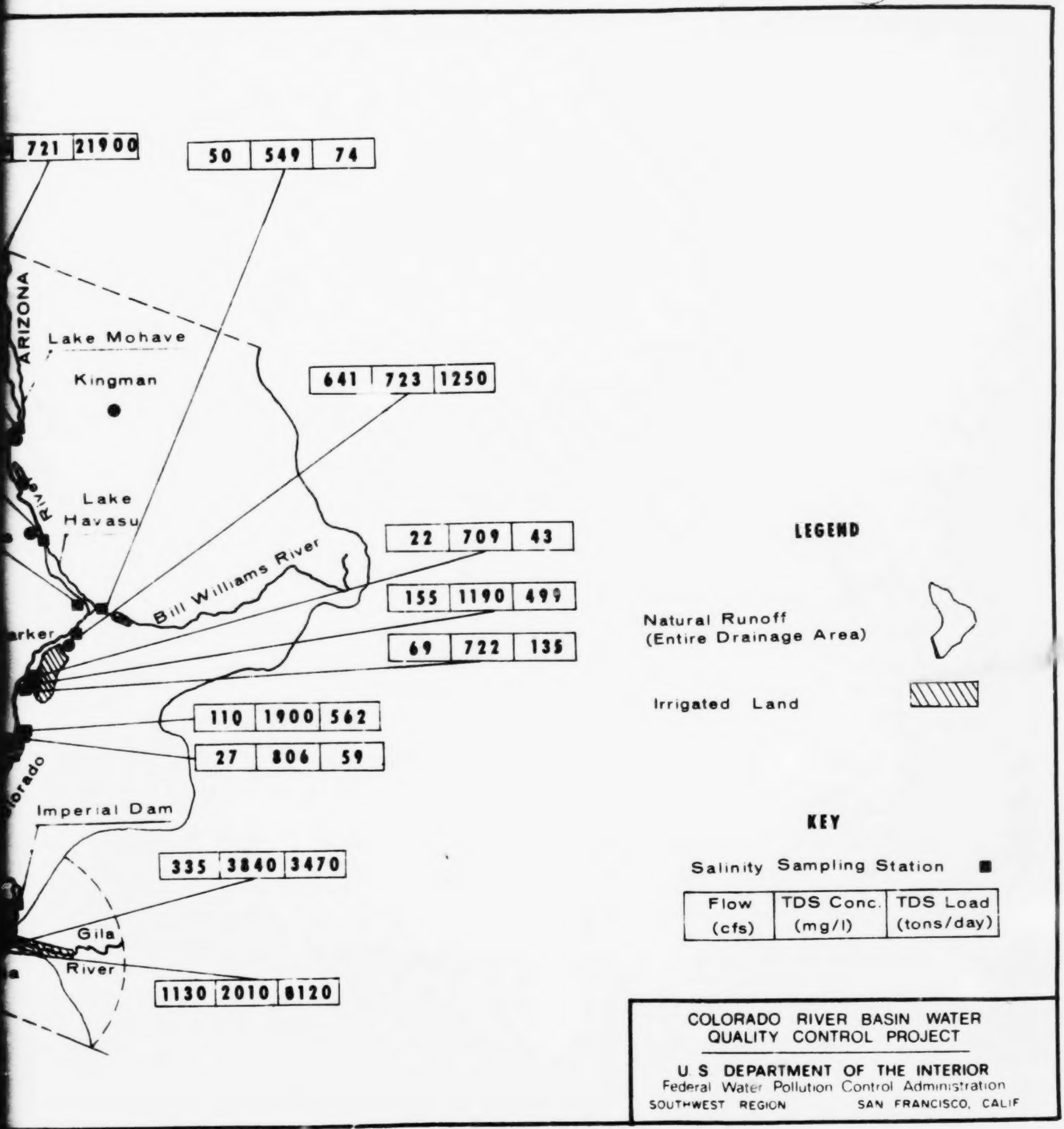

11200 | 726 | 21900
11400 | 721 | 21900
50 | 549 | 74
11200 | 726 | 21900
NEVADA
ARIZONA
1520 | 725 | 2970
Lake Mohave
Kingman
641 | 72
1330 | 673 | 2770
River
Lake
Havasu
Needles
7610 | 755 | 15500
Bill Williams River
Parker
564 | 1670 | 2540
8280 | 822 | 18400
110 | 1900 | 562
Blythe
27 | 806 | 59
718 | 840 | 1630
Colorado
CALIFORNIA
Imperial Dam
717 | 896 | 1740
335 | 3840 | 3470
2180 | 1430 | 8410
Gila
River
Yuma
1130 | 2010 | 8120
San Luis

Figure 43 Flow and Quality at Key Sampling Stations and Location of Pri
Below Hoover Dam. Lower Colorado River Basin. 196

B


721 | 21900
50 | 549 | 74
ARIZONA
Lake Mohave
Kingman
641 | 723 | 1250
Lake Havasu
River
Bill Williams River
22 | 709 | 43
155 | 1190 | 499
69 | 722 | 135
arker
110 | 1900 | 562
27 | 806 | 59
olorado
Imperial Dam
335 | 3840 | 3470
Gila River
1130 | 2010 | 8120
LEGEND
Natural Runoff (Entire Drainage Area)
Irrigated Land ▨
KEY
Salinity Sampling Station ■
Flow (cfs) | TDS Conc. (mg/l) | TDS Load (tons/day)
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

ampling Stations and Location of Principal Salinity Sources
m. Lower Colorado River Basin. 1963-64

springs below Willow Beach. The decrease in flow is well within the range of accuracy of flow measurement at the two stations, but may actually reflect some losses due to the phreatophyte growth within the reach.

In the river reach between Davis Dam and Parker Dam, the Metropolitan Water District of Southern California (MWD) diverted 1520 cfs and 2770 tons of salt per day during the study period. The analytical methods employed by MWD in determining TDS concentrations at Parker Dam utilized a calculation of the sum of the constituent ions which caused the reported concentration to be slightly lower than that at upstream and downstream stations. On the basis of residue concentrations, the diverted load was on the order of 3,000 tons per day. Municipal discharge from Needles, California, added 1 cfs and 4 tons of salt per day. The Bill Williams River discharged a mean flow of 50 cfs at a TDS concentration of 549 mg/l and contributed 74 tons of salt per day to the river system. The salt load contributed by the Bill Williams River was virtually all from natural sources. During the study period, water levels in Lake Mohave and Lake Havasu increased as additional water was stored. It is estimated that decreases in flow due to evaporation and bank storage within the reach totaled 620 cfs during the study period. Bank storage of salt load was estimated at 724 tons per day. The additional losses of 60 cfs and 110 tons of salt per day were apparently caused by the increase in storage in Lake Mohave and Lake Havasu during the study period.

Between Parker Dam and Imperial Dam there are no major flowing tributaries and no significant discharges of salt loads from natural sources.

The Colorado River Indian Reservation (CRIR) on the Arizona side of the river near Parker, Arizona, and the Palo Verde Irrigation District (PVID) in California near the town of Blythe, returned irrigation drainage, spillage of excess water from canals, and groundwater from drainage wells to the Colorado River.

The CRIR, with 31,940 acres under irrigation, consumed 187,300 acre-feet of water and contributed a salt load of 48 tons per day or an average of 0.5 tons per acre per year.

The Palo Verde Irrigation District, with approximately 84,300 acres under irrigation, consumed 366,000 acre-feet of water and contributed a salt load of 492 tons per day, an average of 2.1 tons per acre per year. Much of the salt addition from the Palo Verde Irrigation District resulted from lowering of the groundwater table by deepening of existing drains which resulted in removal of salt previously stored in the irrigated area. With adequate drainage, the salt yield from PVID would be expected to approximate that from the Colorado River Indian Reservation. Irrigation of a small area in Cibola Valley may also contribute some salt load to the Colorado River through diffuse seepage.

A summation of the salt loads and discharge gains and losses between Parker Dam and Imperial Dam revealed a loss of 242 cfs and a salt load gain of 100 tons per day. Calculations indicate that transpiration from 41,600 acres of phreatophyte growth and evaporation from the 9,600 acres of free water surface within the reach consumed 240,000 acre-feet of water during the year of study. Ungaged inflow within the reach, due to seepage from irrigated areas, was calculated at 60,000 acre-feet. Local precipitation and runoff contributed 13,000 acre-feet. The ungaged inflow of 73,000 acre-feet plus the previously cited loss in flow over the reach totaled 258,000 acre-feet. This approximated the calculated losses due to evapotranspiration.

Chemical composition of the Colorado River in the reach between Parker Dam and Imperial Dam reflected the inflow of drainage from irrigated areas having high sodium and chloride concentrations (Figure 50). The chemical composition of drainage from the Upper Main Drain on the CRIR had the same relative proportions as water of the Colorado River but all concentrations were slightly higher. Drainage from the Lower Main Drain on the CRIR was predominantly sodium-chloride-sulfate type water. These observations are in keeping with the history of irrigation development on the CRIR. Lands drained by the Upper Main Drain have been irrigated for a number of years and are well leached. Some of the lands drained by the Lower Main Drain were receiving initial leaching during the period of study. Sodium, chloride, and sulfate were predominant in drainage water from the Palo Verde Irrigation District. As indicated earlier, the higher TDS concentrations were related to the deepening of drains within that area.

Of the 8,280 cfs and 18,770 tons of salt per day reaching Imperial Dam during the study period, 718 cfs and 1,630 tons per day continued down the Colorado River channel; 1,240 cfs and 2,810 tons per day were diverted into the Gila Main Gravity Canal; and 6,320 cfs and 14,330 tons were diverted into the All American Canal.

Between Imperial Dam and the Northerly International Boundary, flow and salt load in the river increased by 1,460 cfs and 6,780 tons per day. These increases were attributable to numerous canal and irrigation returns to the river. The measured contributions are summarized in the following tabulation.

Source	Discharge (cfs)	TDS Load (tons/day)
Laguna Canal Wasteway	5.7	14
Levee Canal Wasteway	17.6	40
North Gila Drain	11.2	44
Gila River (incl. Wellton-Mohawk Drainage as well as South and North Gila Valley	335	3,470
Yuma Main Canal Wasteway	117	265
Reservation Drain No. 4	62.7	196
Drain 8-B	4.7	12
Pilot Knob Wasteway	806	1,830
Total	1,359.9	5,871

It is emphasized that the above tabulation lists gross returns to the river. Net measured changes in flow and salt load due to irrigation within the reach were a depletion of 1,160 cfs and an addition of 530 tons per day. Domestic use of water at Yuma added a salt load of 17 tons per day to the reach. The totals in the tabulation leave an unaccounted ungaged increase in flow of 100 cfs and increase in salt load of 910 tons per day. These increases are believed to be mainly due to seepage from intensive irrigation within the reach although some of the increase may be due to normal errors in flow measurements and laboratory analyses on the many measured returns shown in the tabulation.

Subsequent to completion of the Project's studies in the Lower Basin, the Wellton-Mohawk Main Outlet Drain was extended to the Northerly International Boundary where the Mexican government exercises the option of accepting the highly saline water above or below Morelos Dam.

No attempt was made to develop water and salt budgets for the Colorado River downstream of the Northerly International Boundary. Return flows to the Colorado River include the Cooper Wasteway which returned 5 tons of salt per day; the 11-Mile Wasteway, returning 28 tons of salt per day; and the 21-Mile Wasteway, discharging 19 tons of salt per day. The Yuma Project Valley Division Main Drain and the East Main Canal join at the Southerly International Boundary and cross into Mexico at San Luis Sonora. The Main Drain discharged 187 cfs and 796 tons of salt per day, and the East Main Canal discharged 12.2 cfs and 40 tons of salt per day during the study period. In summary, discharges at the Northerly International Boundary returns to the Limatrophe Section, and discharges at the Southerly International Boundary totaled 2,400 cfs with a salt load of 9,300 tons per day during the study period.

Chemical composition of the Colorado River, between Imperial Dam and the Northerly International Boundary, became predominantly sodium, chloride, and sulfate as a result of the highly saline inputs from the lower Gila River and the Wellton-Mohawk Irrigation District (Figure 50). Extension of the Wellton-Mohawk Main Outlet Drain to the Northerly Border has ameliorated this unfavorable condition in the immediate reach of the Colorado River.

SUMMARY OF FINDINGS FOR ENTIRE COLORADO RIVER BASIN

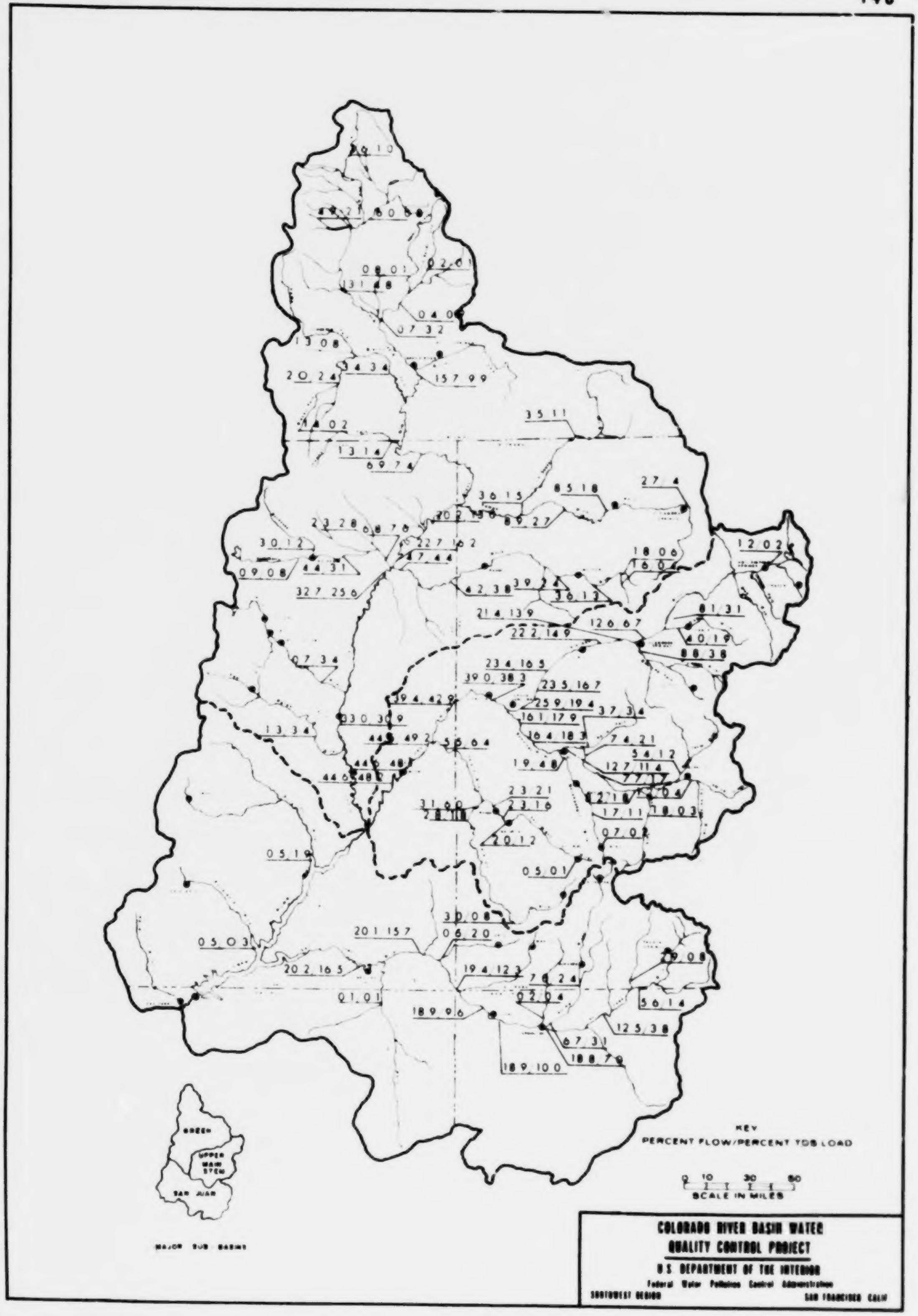
During the period June 1965 through May 1966, the mean annual flow from the Upper Colorado River Basin was 19,263 cfs. The salt load discharged into Lake Powell during the same period averaged 26,160 tons per day. The flow and salt load contributed by each of three major subbasins is shown in the following tabulation.

Subbasin	Flow: cfs	Flow: Percent of Upper Basin Outflow	Salt Load: Tons/day	Salt Load: Percent of Upper Basin Outflow
Upper Main Stem	8,582	44.5	12,587	48.1
Green River	6,600	34.3	9,020	34.5
San Juan River	4,081	21.2	4,553	17.4
Total	19,263		26,160	

The percentage of total Upper Basin mean daily flow and salt load passing key stations is shown in Figure 44.

Runoff, including both overland runoff and groundwater inflow to streams, contributed 52 percent of the salt load from the Upper Colorado River Basin. The mountainous headwaters areas, consisting of insoluble rocks of highly resistant outcrops, yielded large quantities of good quality water. The lower valley areas, composed of more soluble sediments, contributed small amounts of highly mineralized water. It became clear that contact of water with the saline geologic formations of the Upper Basin, whether from natural precipitation or from irrigation, caused serious degradation of water quality in the streams receiving runoff or drainage from these formations.

In the Lower Colorado Basin, consumptive use of water greatly exceeded inflow to the river system and salt sources within the Basin added an estimated 5,484 tons per day to the stream system. Approximately three-fourths of the salt load and virtually all of the flow in the Lower Colorado Basin was discharged from the Upper Basin. The relative magnitudes of salt loads contributed by various types of sources in the Colorado River Basin are summarized graphically in Figure 45. The percentage of Lower Basin flow and load passing key sampling stations is shown in Figure 46.


35,11
27,4
12,02
18,06
16,04
81,31
40,19
88,38
126,67
214,139
222,149
234,165
390,383
235,167
259,194
161,179
164,183
37,3
74,21
54,12
127,114
18,03
17,11
07,02
05,01
23,21
23,16
20,12
19,48
30,08
06,20
201,157
202,165
194,123
01,01
189,96
189,100
67,31
188,79
125,38
56,14
05,03
05,19
13,34
07,34
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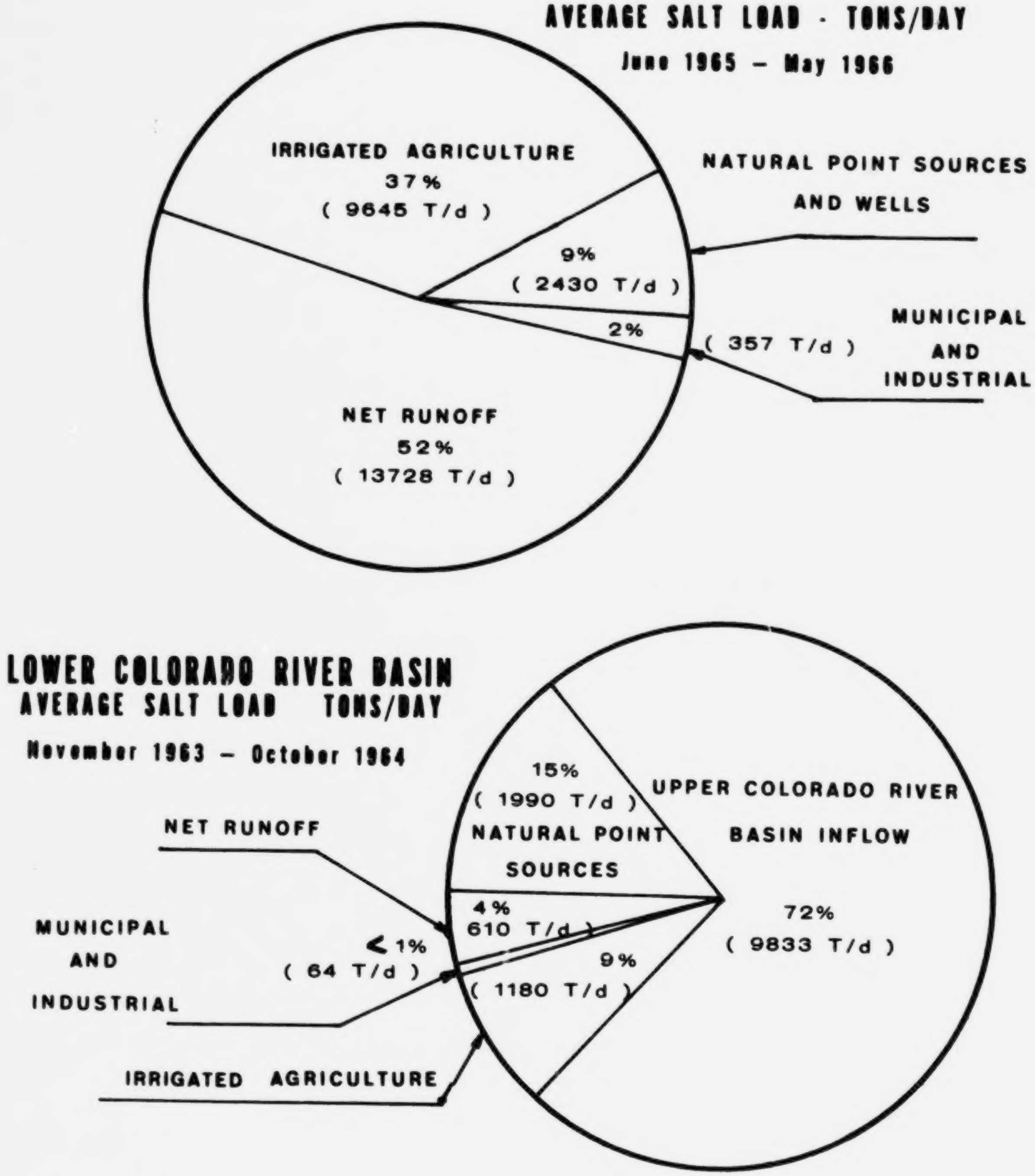
09,08
44,31
23,28
68,78
202,156
227,162
174,4
36,15
85,18
89,27
42,38
39,2
36,13
13,14
69,74
20,24
34,34
157,99
13,08
04,0
07,32
08,01
02,01
31,48
394,429
330,309
55,64
446,482
KEY
PERCENT FLOW/PERCENT TDS LOAD
0 10 30 50
SCALE IN MILES
GREEN
UPPER MAIN STEM
SAN JUAN
MAJOR SUB BASINS
COLORADO RIVER BASIN WATER
QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO CALIF

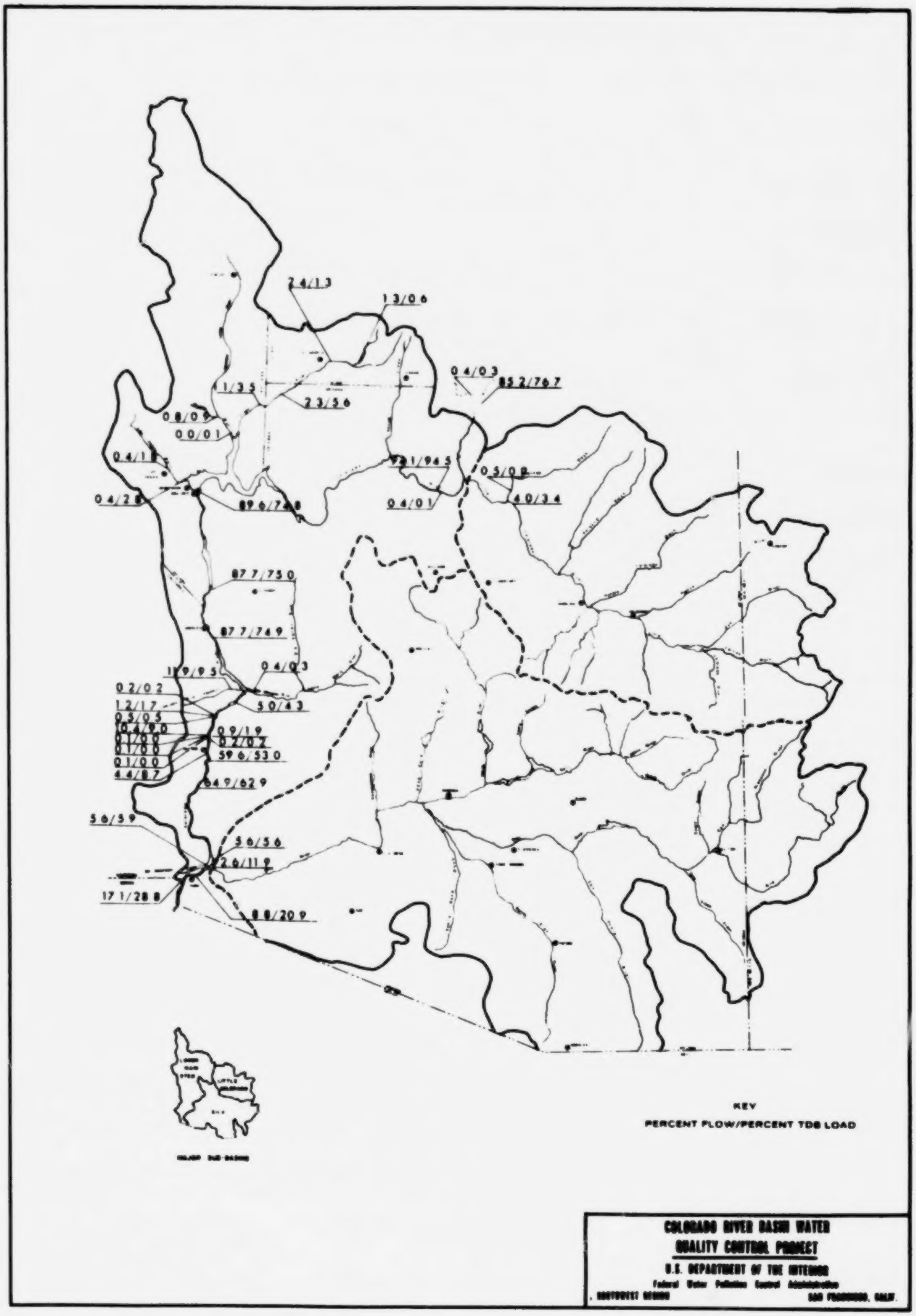
Figure 44 Percent of Average Daily Flow and TDS Load Entering Lake Powell,1965-66-



UPPER COLORADO RIVER BASIN
AVERAGE SALT LOAD - TONS/DAY
June 1965 – May 1966

LOWER COLORADO RIVER BASIN
AVERAGE SALT LOAD TONS/DAY
November 1963 – October 1964

Figure 45 Relative Magnitude of Salt Sources in the Colorado River Basin


2.4/1.3
1.3/0.6
0.4/0.3
85.2/76.7
1.1/3.5
2.3/5.6
0.8/0.9
0.0/0.1
0.4/1.5
92.1/94.5
0.5/0.8
4.0/3.4
0.4/2.8
89.6/74.8
0.4/0.1
87.7/75.0
87.7/74.9
11.9/9.5
0.4/0.3
0.2/0.2
1.2/1.7
0.5/0.5
10.4/9.0
0.1/0.0
0.1/0.0
0.1/0.0
4.4/8.7
5.0/4.3
0.9/1.9
0.2/0.2
59.6/53.0
64.9/62.9
5.6/5.9
5.6/5.6
2.6/11.9
17.1/28.8
8.8/20.9
LITTLE COLORADO
GILA
MAJOR SUB-BASINS
KEY
PERCENT FLOW/PERCENT TDS LOAD

COLORADO RIVER BASIN WATER
QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION SAN FRANCISCO, CALIF.

Figure 46 Percent of Average Daily Flow and Load Entering the Colorado River below Lees Ferry, 1963-64

Irrigation contributed 37 percent of the salt load produced in the Upper Colorado River Basin. The salt load contributions and average salt yields from the major irrigated areas in the three subbasins are given by Table 5. Salt load contributions from the major irrigated areas in the Colorado River Basin are compared graphically in Figure 47.

Irrigation adjacent to the reach of the Colorado River between Hoover Dam and the Southerly International Boundary caused a net depletion of 1928 cfs in the Colorado River, and a net salt load addition to the stream of 1068 tons per day during the study period. The relative salt yields from these areas are summarized in Table 6. The range of salt load yields from the principal irrigated areas in the Colorado River Basin is shown in Figure 48.

Point sources such as springs, wells, and abandoned oil-test holes, contributed 10 percent of the salt load in the Upper Basin. The significant point sources of salinity and their respective salt loads are given in Table 7.

Springs added more salt load to the Lower Colorado River Basin than any other type of source. The measured contribution was nearly 2,000 tons of salt per day. Blue Springs, located near the mouth of the Little Colorado River, contributed a salt load of approximately 1,500 tons per day, constituting the largest single point source in the Colorado River Basin. Salt load contributions by major point sources are compared in Figure 49.

Municipal and industrial effluents added only about one percent of the Upper Basin salt load. Salt inputs from oil-field activities were found to be transitory in nature, and may at times, contribute considerably more or less salt to the system than was observed during the study. The

Table 5. Salt Yields and Loads From Irrigation In Green River Subbasin

Area	Salt Load (Tons/Day)	Average Salt Yield (Tons/Acre/Yr)
Green River above New Fork River	30	0.1
Big Sandy Creek	200	5.6
Blacks Fork in Lyman area	475	2.4
Hams Fork	6	0.3
Henry's Fork	244	4.9
Yampa River above Steamboat Springs	20	0.2
ampa River, Steamboat Springs to Craig	24	0.4
Milk Creek	6	1.0
Williams Fork River	13	0.3
Little Sanke above Dixon	15	0.3
Little Sanke, Dixon to Baggs	25	0.5
Ashley Creek	230	4.2
Duchesne River	1350	3.0
White River below Meeker	20	2.0
Price River	580	8.5
San Rafael River	290	2.9
Total	3,528	
Percent of Green River Subbasin Salt Load	39.2	
Percent of Total Upper Basin Salt Load	13.5	

Table 5 (Cont'd.). Salt Yields and Loads From Irrigation In Upper Main Stem Subbasin

Area	Salt Load (Tons/Day)	Average Salt Yield (Tons/Acre/Yr)
Main Stem above Hot Sulphur Springs	15	0.3
Main Stem, Hot Sulphur Springs to Kremmling	61	0.9
Muddy Creek Drainage Area	46	2.4
Brush Creek	10	0.7
Roaring Fork River	200	3.5
Colorado River Valley, Glenwood Springs to Silt	100	2.3
Colorado River, Silt to Cameo	30	3.5
Grand Valley	1,925	8.0
Plateau Creek	75	0.9
Gunnison River above Gunnison	9	0.3
Tomichi Creek above Parlin	6	0.3
Tomichi Creek, Parlin to mouth	6	0.3
Uncompahgre above Dallas Creek	74	4.5
Lower Gunnison	3,000	6.7
Naturita Creek near Norwood	46	2.8
Total	5,603	
Percent of Upper Colorado River Subbasin Salt Load	44.5	
Percent Total of Upper Basin Salt Load	21.5	

Table 5 (Cont'd.). Salt Yields and Loads From Irrigation In San Juan River Subbasin

Area	Salt Load (Tons/Day)	Average Salt Yield (Tons/Acre/Yr)
Fremont River above Torrey, Utah	20	0.4
Fremont River, Torrey to Hanksville, Utah	16	5.8
Muddy Creek above Hanksville, Utah	60	3.1
San Juan above Carracas	104	2.7
Florida, Los Pinos, Animas drainage	33	0.2
Lower Animas Basin	165	3.5
LaPlata River in Colorado	56	1.4
LaPlata River in New Mexico	4	0.3
Total	518	
Percent of San Juan Subbasin Salt Load	12.9	
Percent Total of Upper Basin Salt Load	1.9	

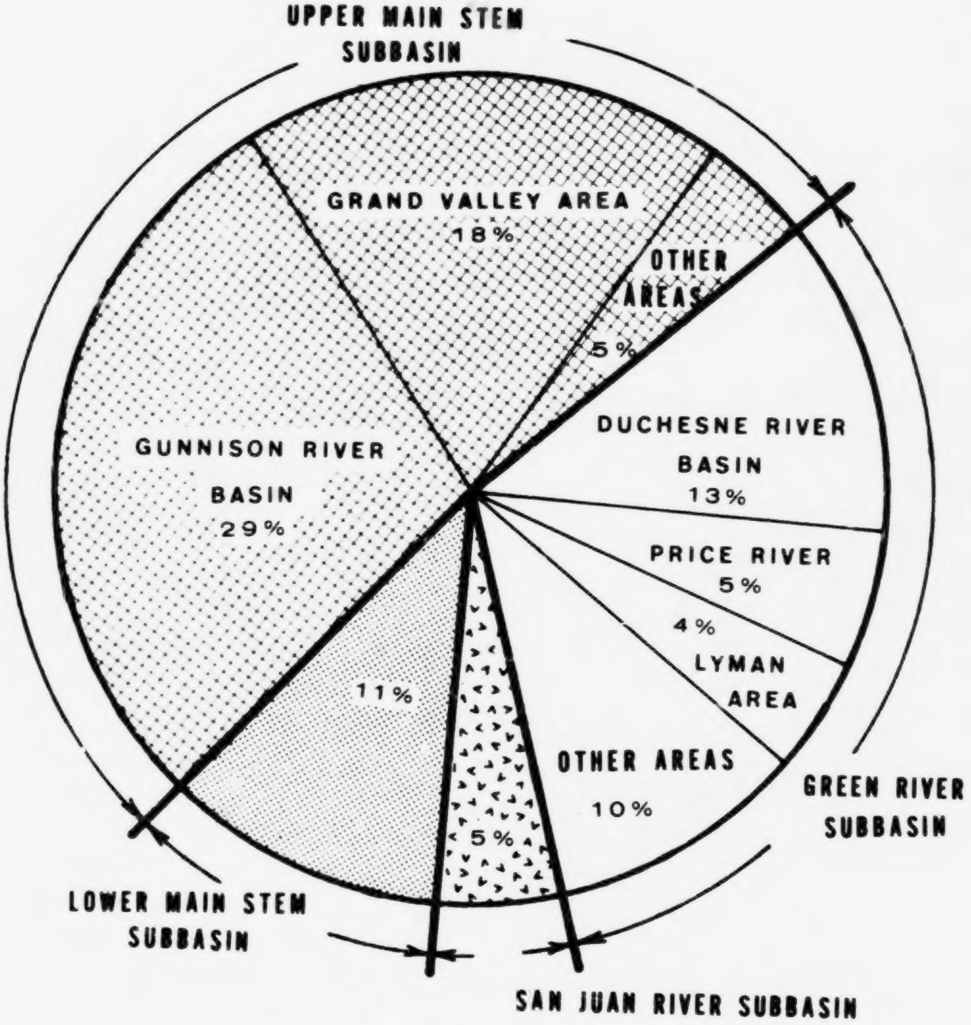


Figure 47 Relative Salt Loads from Irrigated Areas in Colorado River Basin

Table 6. Salt Yields and Loads From Irrigation In Lower Colorado River Basin

Area	Salt Load (Tons/Day)	Average Salt Yield (Tons/Acre/Yr)
Virgin River	112	2.3
Colorado River Indian Reservation	48	0.5
Palo Verde Irrigation District	490	2.1
Below Imperial Dam (Gila and Yuma Projects)	530	Variable
Total	1,180	

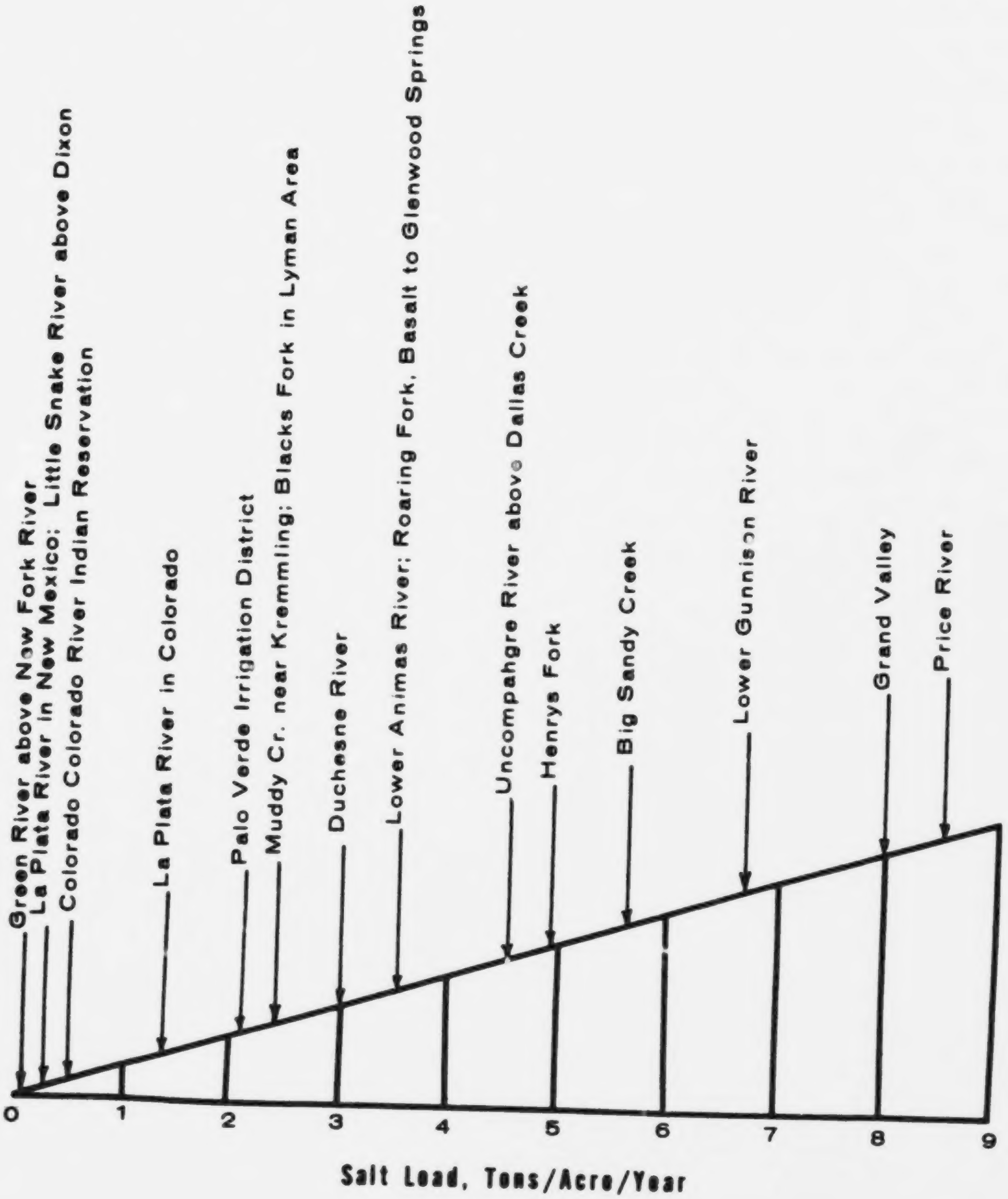


Figure 48 Observed Range of Salt Yields from Irrigated Areas in the Colorado River Basin

Table 7. Salt Load Contributions From Major Point Sources in Colorado River Basin

Source	Salt Load (Tons/Day)
Green River Subbasin	
Warm Kendall Spring	18
Cold Kendall Spring	8
Coal Mine Drainage near Oak Creek, Colorado	6
Steamboat Springs Mineral Springs	24
Jones Hole Creek-Whirlpool Canyon	21
Split Mountain Warm Springs	51
Test Hole near Jensen, Utah	1
Stinking Spring	1
Indian Creek Springs	3
Meeker Oil Test Hole	160
Piceance Creek Well	17
Crystal Geyser	53
Total	363
Upper Main Stem	
Hot Sulphur Springs	0
Dotsero Spring	440
Glenwood Springs Area	920
Ouray Hot Springs	4
Ridgeway Hot Springs	7
Paradise Hot Spring	2
Paradox Valley	688
Total	2,061
San Juan Subbasin	
Pagosa Hot Springs	20
Pinkerton Hot Spring	5
Total	25
Lower Colorado River Basin	
Blue Springs	1,500
Miscellaneous small springs above Grand Canyon	10
Vulcan or Lava Falls Spring	10
Miscellaneous springs above Virgin River	21
Havasu Spring	65
LaVerkin Spring	286
Littlefield Salt Springs	81
Rogers Spring	17
Total	1,990

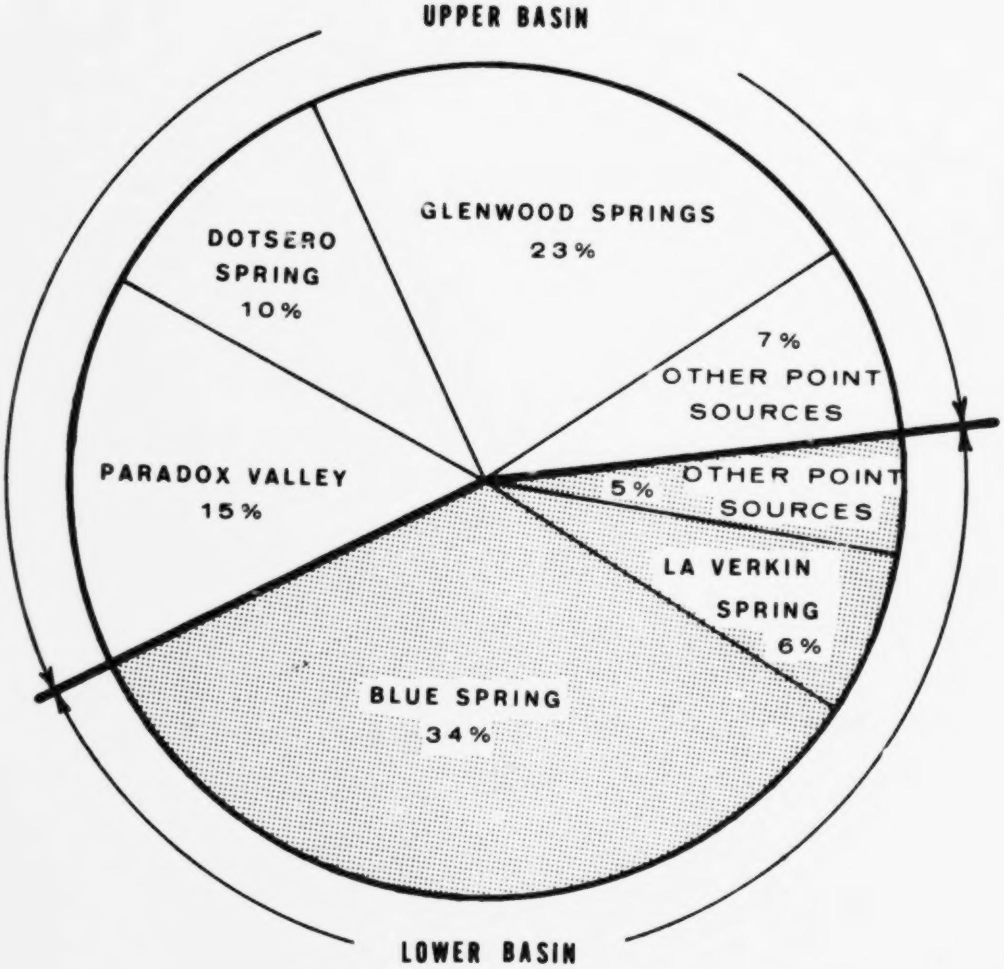


Figure 49. Comparison of Salt Loads from Point Sources in the Colorado River Basin

principal industrial and oil-field sources and their observed yields, are shown in Table 8.

Municipal and industrial waste discharges added 64 tons of salt per day to the Lower Colorado River. Seepage from ponds containing municipal and industrial wastes contributed a portion of the 400 tons per day input from Las Vegas Wash.

Headwater areas of streams in the Upper Basin, with few exceptions, yield predominantly calcium-bicarbonate type water. The use of these waters for irrigation of well-leached soils in upland areas did not seriously alter the chemical composition of the streams. Leaching of saline sediments in the lower valleys caused the waters to become predominantly sodium-calcium-sulfate type, in stream reaches below such areas where precipitation and/or applied irrigation water came into contact with these geological formations. The Mancos shale, the Paradox formation, and various saline Tertiary-age lakebed formations had the most serious effect on the chemical composition of streams. The effects of major springs and industrial effluents were discerned in the chemical composition of small receiving streams, but were essentially masked in the larger streams. Figures 51, 52, and 53 show the chemical composition of streams at key sampling stations in the Upper Basin.

The relative proportions of chemical constituents remained surprisingly consistent in the Lower Colorado River between Lee's Ferry and the mouth of the Gila River (Figure 50). Drainage containing predominantly calcium-sodium-sulfate-chloride type waters was discharged from newly irrigated lands on the lower portion of the Colorado River Indian Reservation, and from newly deepened drains in the Palo Verde Irrigation

Table 8. Salt Loads From Principal Industrial Sources, Colorado River Basin

Source	Salt Load (Tons/Day)
Green River Subbasin	
Flood Wash near Wellington, Utah	13
Iles Dome Oil Field water, Colorado	17
Ashley Valley Oil Field water, Utah	32
Total	62
Upper Main Stem	
New Jersey Zinc tailings decant, Gilman, Colorado	10
Union Carbide uranium mill effluent, Rifle, Colorado	40
Climax uranium mill effluent, Grand Junction, Colorado	35
American Gilsonite refinery effluent, Fruita, Colorado	9
Union Carbide uranium mill effluent, Uravan, Colorado	119
Atlas Mineral Corporation uranium mill effluent, Moab, Utah	36
Total	249
San Juan Subbasin	
Four Corners Power Plant, Shiprock, New Mexico	35
Foote Mineral Corporation uranium mill effluent Shiprock, New Mexico	11
Total	46

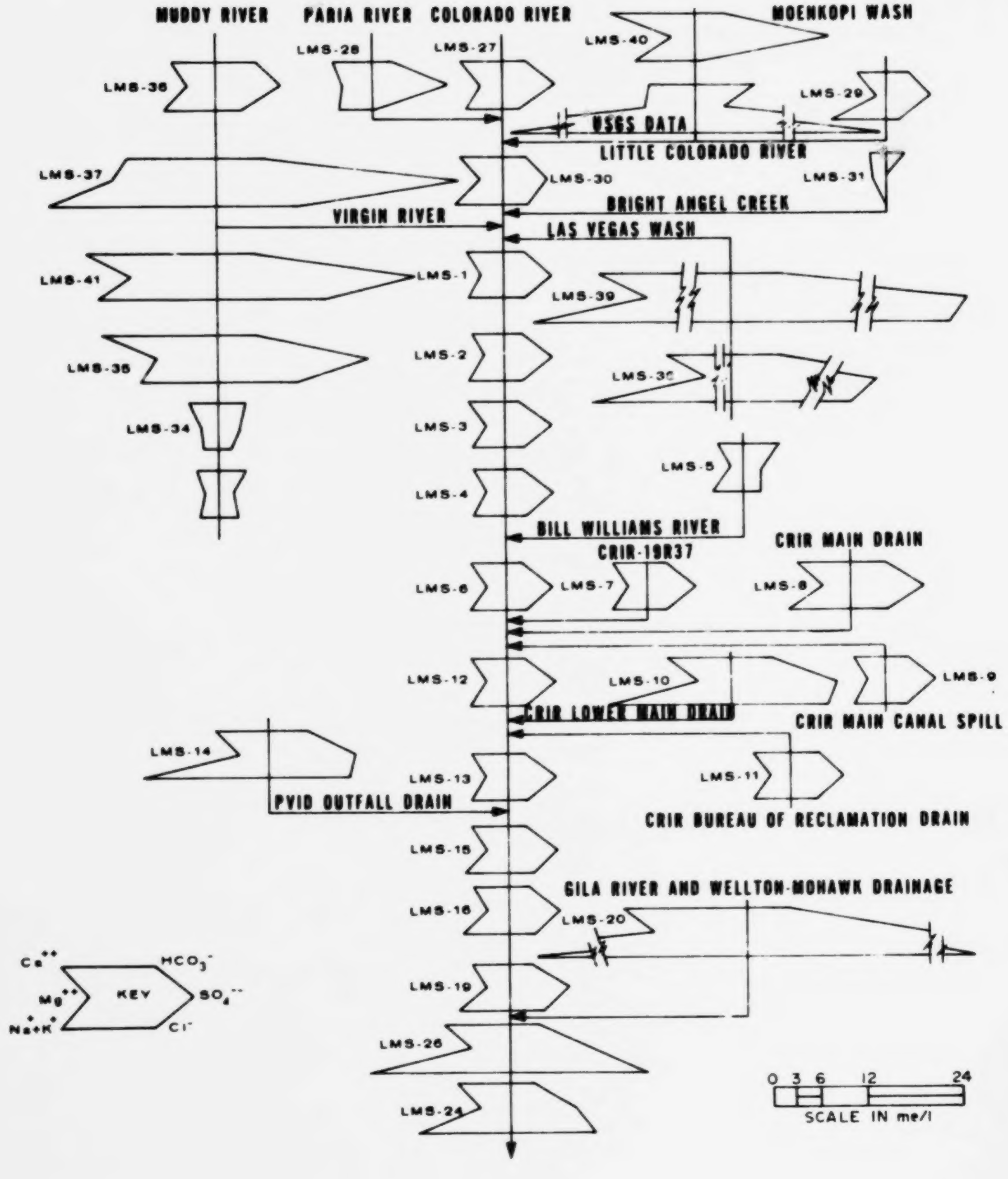

MUDDY RIVER
PARIA RIVER
COLORADO RIVER
MOENKOPI WASH
LMS-40
LMS-28
LMS-27
LMS-36
LMS-29
USGS DATA
LITTLE COLORADO RIVER
LMS-37
LMS-30
LMS-31
BRIGHT ANGEL CREEK
VIRGIN RIVER
LAS VEGAS WASH
LMS-41
LMS-1
LMS-39
LMS-35
LMS-2
LMS-38
LMS-34
LMS-3
LMS-5
LMS-4
BILL WILLIAMS RIVER
CRIR-19R37
CRIR MAIN DRAIN
LMS-6
LMS-7
LMS-8
LMS-12
LMS-10
LMS-9
CRIR LOWER MAIN DRAIN
CRIR MAIN CANAL SPILL
LMS-14
LMS-13
LMS-11
PVID OUTFALL DRAIN
CRIR BUREAU OF RECLAMATION DRAIN
LMS-15
GILA RIVER AND WELLTON-MOHAWK DRAINAGE
LMS-16
LMS-20
LMS-19
LMS-26
LMS-24
Ca++
Mg++
Na+K+
KEY
HCO3-
SO4--
Cl-
0 3 6 12 24
SCALE IN me/l

Figure 50 Ionic Concentration Diagrams for the Lower Main Stem Subbasin

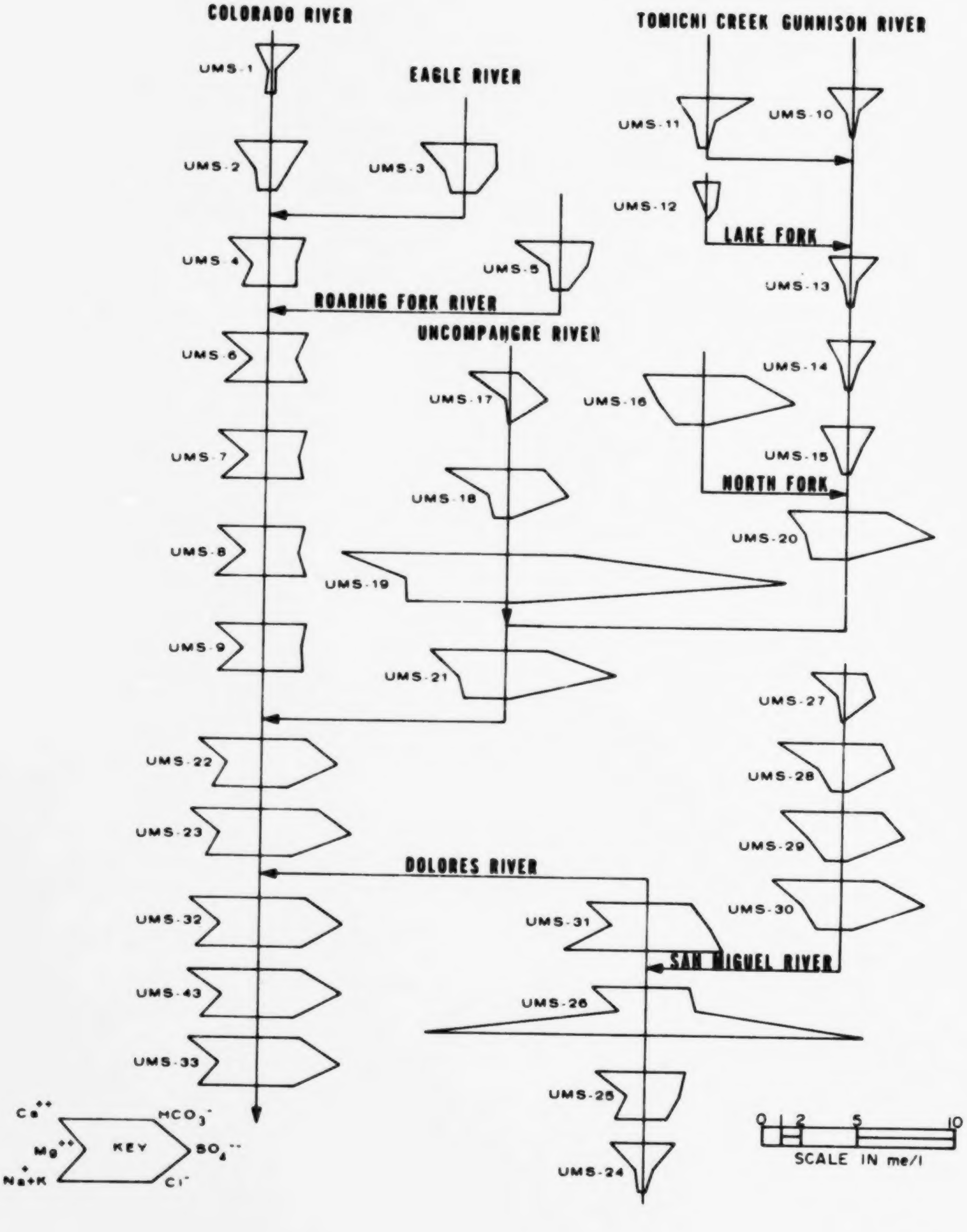

COLORADO RIVER
EAGLE RIVER
TOMICHI CREEK
GUNNISON RIVER
UMS-1
UMS-2
UMS-3
UMS-4
UMS-5
ROARING FORK RIVER
UMS-6
UNCOMPAHGRE RIVER
UMS-7
UMS-8
UMS-9
UMS-10
UMS-11
UMS-12
LAKE FORK
UMS-13
UMS-14
UMS-15
UMS-16
NORTH FORK
UMS-17
UMS-18
UMS-19
UMS-20
UMS-21
UMS-22
UMS-23
DOLORES RIVER
UMS-24
UMS-25
UMS-26
UMS-27
UMS-28
UMS-29
UMS-30
UMS-31
SAN MIGUEL RIVER
UMS-32
UMS-43
UMS-33
Ca^{++}
Mg^{++}
$Na+K$
KEY
HCO_3^-
SO_4^{--}
Cl^-
0
2
5
10
SCALE IN me/l

Figure 51 Ionic Concentration Diagrams for the Upper Main Stem Subbasin

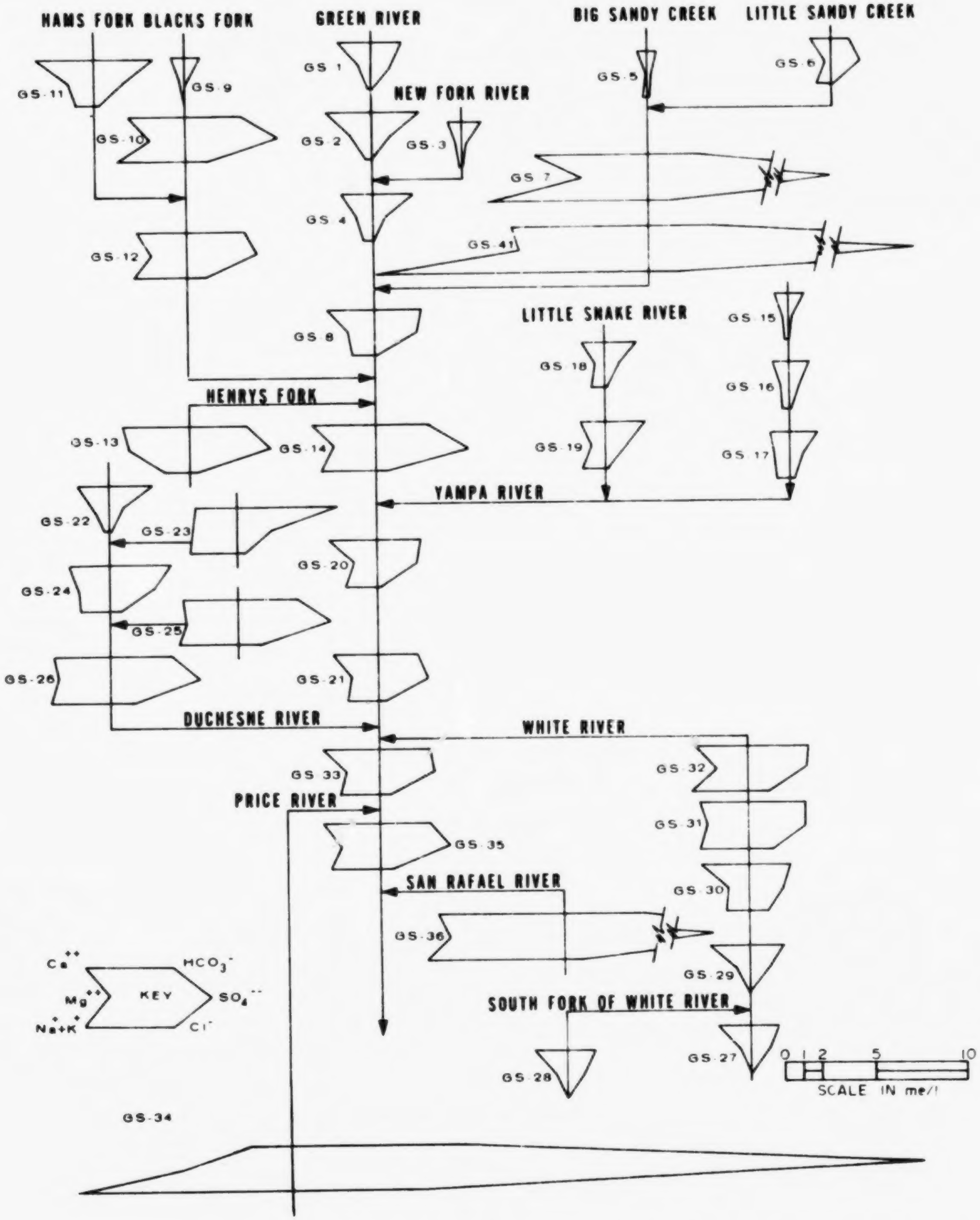

HAMS FORK
BLACKS FORK
GREEN RIVER
BIG SANDY CREEK
LITTLE SANDY CREEK
NEW FORK RIVER
GS-1
GS-2
GS-3
GS-4
GS-5
GS-6
GS-7
GS-8
GS-9
GS-10
GS-11
GS-12
GS-41
LITTLE SNAKE RIVER
GS-15
GS-16
GS-17
GS-18
GS-19
HENRYS FORK
GS-13
GS-14
YAMPA RIVER
GS-20
GS-21
GS-22
GS-23
GS-24
GS-25
GS-26
DUCHESNE RIVER
WHITE RIVER
GS-32
GS-33
PRICE RIVER
GS-31
GS-35
GS-30
SAN RAFAEL RIVER
GS-36
GS-29
SOUTH FORK OF WHITE RIVER
GS-27
GS-28
GS-34
Ca^{++}
Mg^{++}
$Na^{+}+K^{+}$
KEY
HCO_3^{-}
SO_4^{--}
Cl^{-}
0 1 2 5 10
SCALE IN me/l

Figure 52 Ionic Concentration Diagrams for the Green River Subbasin

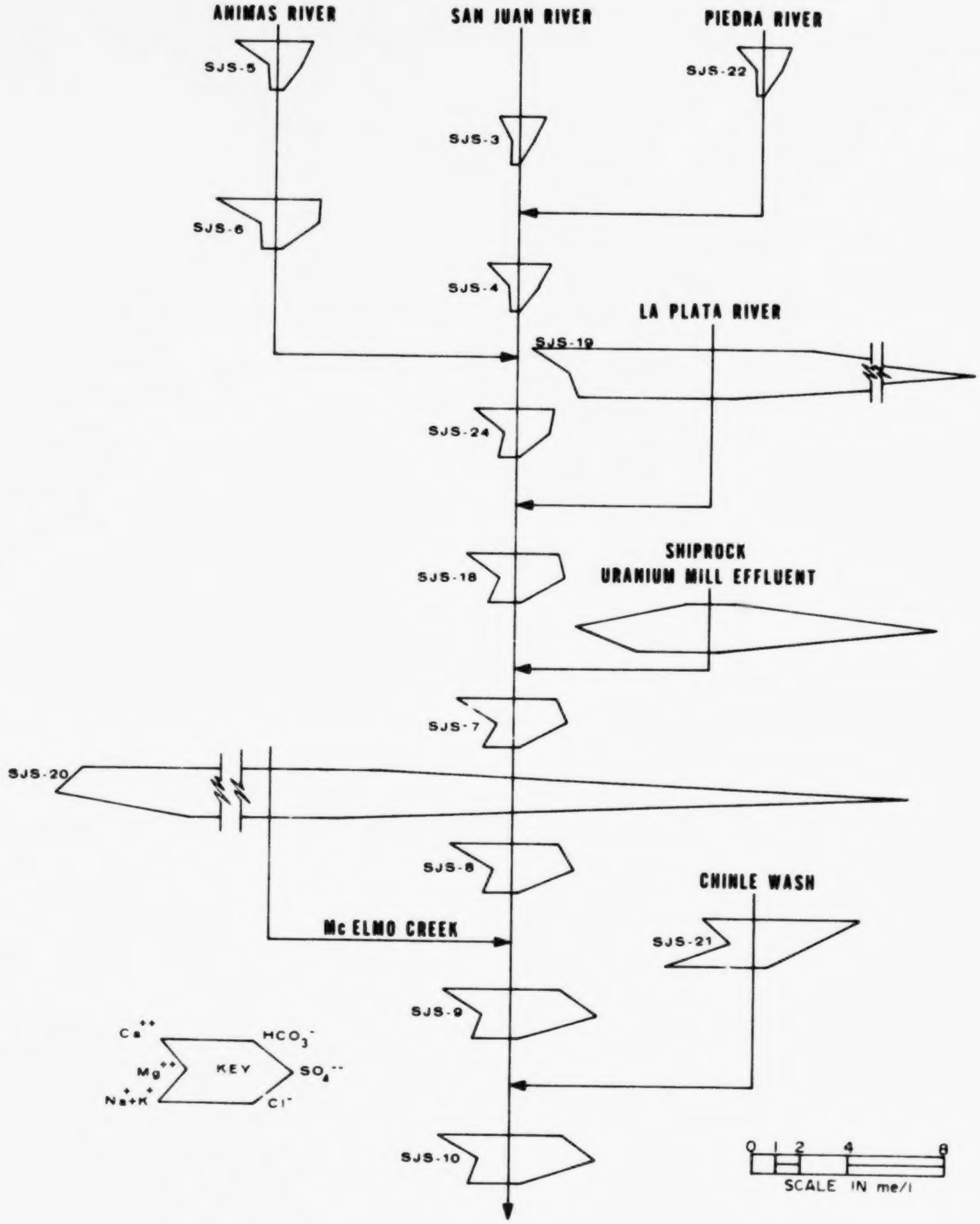

ANIMAS RIVER
SAN JUAN RIVER
PIEDRA RIVER
SJS-5
SJS-22
SJS-3
SJS-6
SJS-4
LA PLATA RIVER
SJS-19
SJS-24
SJS-18
SHIPROCK
URANIUM MILL EFFLUENT
SJS-7
SJS-20
SJS-8
CHINLE WASH
Mc ELMO CREEK
SJS-21
SJS-9
Ca^{++}
HCO_3^-
Mg^{++}
KEY
SO_4^{--}
Na^++K^+
Cl^-
SJS-10
0 1 2 4 8
SCALE IN me/l

Figure 53 Ionic Concentration Diagrams for the San Juan River Subbasin

District. These inputs were not of sufficient magnitude to significantly alter the chemical composition of the Colorado River. Large quantities of predominantly sodium-chloride type water discharged from the Wellton-Mohawk Main Outlet Drain caused the Colorado River water to become predominantly sodium-chloride type in the reach between the mouth of the Gila River and the Northerly International Boundary.

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☆ GPO 790-010

THE MINERAL QUALITY PROBLEM
IN THE COLORADO RIVER BASIN

APPENDIX B

PHYSICAL AND ECONOMIC IMPACTS

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGIONS VIII AND IX

1971

THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency was established by Reorganization Plan No. 3 of 1970 and became operative on December 2, 1970. The EPA consolidates in one agency Federal control programs involving air and water pollution, solid waste management, pesticides, radiation and noise. This report was prepared over a period of eight years by water program components of EPA and their predecessor agencies--the Federal Water Quality Administration, U.S. Department of Interior, April 1970 to December 1970; the Federal Water Pollution Control Administration, U.S. Department of Interior, October 1965 to April 1970; the Division of Water Supply and Pollution Control, U.S. Public Health Service, prior to October 1965. Throughout the report one or more of these agencies will be mentioned and should be considered as part of a single agency--in evolution.

PREFACE

The Colorado River Basin Water Quality Control Project was established as a result of recommendations made at the first session of a joint Federal-State "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and its Tributaries," held in January of 1960 under the authority of Section 8 of the Federal Water Pollution Control Act (33 U.S.C. 466 *et seq.*). This conference was called at the request of the states of Arizona, California, Colorado, Nevada, New Mexico, and Utah to consider all types of water pollution in the Colorado River Basin. The Project serves as the technical arm of the conference and provides the conferees with detailed information on water uses, the nature and extent of pollution problems and their effects on water users, and recommended measures for control of pollution in the Colorado River Basin.

The Project has carried out extensive field investigations along with detailed engineering and economic studies to accomplish the following objectives:

(1) To determine the location, magnutide, and causes of interstate pollution of the Colorado River and its tributaries.

(2) To determine and evaluate the nature and magnitude of the damages to water users caused by various types of pollution.

(3) To develop, evaluate, and recommend measures and programs for controlling or minimizing interstate water pollution problems.

In 1963, based upon recommendations of the conferees, the Project began detailed studies of the mineral quality problem in the Colorado River Basin. Mineral quality, commonly known as salinity, is a complex Basin-wide problem that is becoming increasingly important to users of Colorado River water. Due to the nature, extent, and impact of the salinity problem, the Project extended certain of its activities over the entire Colorado River Basin and the Southern California water service area.

The more significant findings and data from the Project's salinity studies and related pertinent information are summarized in a report entitled, "The Mineral Quality Problem in the Colorado River Basin." Detailed information pertaining to methodology and findings of the Project's salinity studies is presented in three appendices to that report - Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality," Appendix B, "Physical and Economic Impacts," and Appendix C, "Salinity Control and Management Aspects."

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CHAPTER I. INTRODUCTION

Salinity is one of the most serious water quality problems in the Colorado River Basin. Like many streams in the arid West, the Colorado River displays a progressive increase in salinity (total dissolved solids)[1] between its headwaters and its mouth. Salinity concentrations in the Lower Colorado River (below Lees Ferry, Arizona) are approaching critical levels for municipal, industrial, and agricultural water use. In the face of this present situation, planned and proposed water resource developments, primarily in the Upper Basin, will cause further increases in salinity concentrations in the Lower Colorado River.

As a part of its overall study of the salinity problem, the Colorado River Basin Water Quality Control Project (Project) carried out detailed studies to evaluate the physical and economic impacts associated with anticipated degradation in the mineral quality of Colorado River water. The methods of investigation and the results of these studies are presented in this appendix.

Before the impacts associated with degradation in mineral quality could be determined, it was necessary to understand the effect of salinity on various beneficial uses of water The general effects of salinity on domestic, industrial, agricultural, and other beneficial uses are discussed in Chapter II of this appendix. Hardness, a water quality parameter closely related to total dissolved solids (TDS), is also discussed since it has significant effects on domestic and industrial water uses.

---

[1] The terms "salinity" and "total dissolved solids" are used synonymously throughout this report.

The mineral quality conditions presently prevailing at various locations along the river and the conditions likely to occur in the years 1980 and 2010 are described in Cahpter III. In order to determine these conditions, a mathematical flow and salt loading routing model was developed for the Colorado River Basin. Published flow and salinity data supplemented by data collected by the Project were used in this model.

Once the general effects of salinity on beneficial uses of water were identified and the anticipated mineral quality for the river system had been determined, methods were developed to quantify the anticipated quality effects in economic terms. Methods were developed also to determine the direct impact of salinity. The methods and results for the direct penalty-cost evaluation are described in Chapter IV.

The first step in the direct penalty-cost evaluation involved the development of methods for relating increases in TDS to the economic cost which each user would incur. Alternative methods were investigated based on the study of the effects of salinity on beneficial uses of water. After careful analysis, methods were chosen for evaluating the effects on each category of water use. Among factors considered in this analysis were the hydrology of the Basin, the quantities of water used by various users, the economy of the Basin, the population of the Basin, and existing water-treatment technology. The amount and location of direct penalty costs incurred by water users in the Basin were determined by the magnitude of expected salinity increase and the volume of anticipated water use.

In addition to the direct impact of degradation in mineral quality upon water users, there are indirect economic effects upon the regional economy. These indirect effects result from the close interdependence of one industry to another, which causes direct effects on one industry to produce indirect effects on another. The first step in evaluating this impact was to investigate the structure of the economy. An input-output, or transactions, table was constructed to identify the flow of goods and services between groups of industries or sectors. Once constructed, the transactions table became a series of linear simultaneous equations that could be solved with a high-speed digital computer utilizing methods of matrix algebra. Direct changes in the economic structure caused by salinity were thereby translated into indirect, or "multiplier," effects to arrive at the total regional economic impact associated with mineral quality degradation. A final step of the analysis was to determine the sensitivity of the calculations to some of the underlying assumptions which were made. A more detailed discussion of the methods used in calculating the total regional economic impact and the results obtained are presented in Chapter V.

CHAPTER II. EFFECTS OF SALINITY ON BENEFICIAL USES OF WATER

Water polluting substances have been traditionally classified in relation to their degradability, principally by biological and bacteriological processes. Biochemical oxygen demand, coliform density, organic content, and nutrient concentrations are classic pollutant properties that are degradable and subject to natural or man-induced biological treatment. Some pollutants such as synthetic detergents, certain classes of pesticides, or other organic substances are only slightly degradable. A large class of substances, primarily the inorganic or complex organic chemicals, exists that is non-degradable or conservative. Since inorganic chemicals are not degraded by the usual stream purification processes, the concentrations typically increase with each water use as the material moves downstream. In the Colorado River Basin the mineral constituents of total dissolved solids are of prime importance in the class of non-degradable or conservative substances.

The effect of polluting substances is generally discussed in terms of their impact upon water uses. In the case of salinity two general categories of water uses should be distinguished: consumptive and non-consumptive. The former includes agricultural uses, such as irrigation and livestock watering, as well as municipal and industrial uses. The latter comprises such uses as hydroelectric power generation, navigation, water-oriented recreation, fish and wildlife habitat, ground water recharge, silt control, and general water quality control. The division obviously arises from the fact that consumptive uses remove water from the system, whereas the non-consumptive uses utilize water *in situ*. In the following two sections the affected uses in these two categories are discussed in detail.

CONSUMPTIVE USES

Municipal

The use of water for domestic purposes is generally considered to be the highest beneficial use. Standards for drinking water utilized by carriers subject to the Federal Quarantine Regulations have been established and revised by the United States Public Health Service since 1914, the latest being issued in 1962.(1) These standards have been adopted by most states for all public water supplies.

Included in these standards are limits for certain inorganic materials which are mandatory in some cases and recommended in other cases. The level of total hardness in a water supply is of primary interest in assessing water quality effects on domestic use. A single criterion for maximum hardness is not recommended for public supplies by the U. S. Public Health Service since public acceptance varies from community to community and is related to the normal levels for a particular community. However, other publications do contain numerous recommendations for desirable levels of hardness in public water supplies. A number of these recommendations are summarized in "Water Quality Criteria."(2) Also, according to Sawyer(3) waters are normally classified in terms of degree of hardness as follows:

0 - 75 mg/1	Soft
75 - 150 mg/1	Moderately Hard
150 - 300 mg/1	Hard
300 Up	Very Hard

Using these criteria, all raw water supplies derived from the Colorado River at or below Lake Mead would be classified as "very hard."

Also of interest in domestic water supplies are the levels of total dissolved solids. The Public Health Service(1) recommends a limit of 500 mg/l provided that more suitable supplies are not or cannot be made available. A previous issuance of the Drinking Water Standards had permitted a TDS concentration of 1,000 mg/l in the absence of an alternate source, but this provision is not included in the present Public Health Service standards. Increases in the concentration of hardness and salinity can cause damages to municipal water users in five ways discussed in the following sections.

Potable Water Supply. In extreme cases mineralization may render a public water supply unfit or highly undesirable for human consumption. One example of this situation within the Colorado River Basin is the experience at Yuma, Arizona. The penalty costs in this situation could include: (1) the cost of obtaining water rights and developing a new water supply, (2) losses associated with abandoning the existing supply and appanages, and (3) differences in operation and maintenance costs between the old and new water supply facilities.

Water Softening. In communities where water softening is practiced, either by municipal softening or invidivual home water softeners, harder water increases the cost of treatment. Resulting increments of treatment costs can be related to anticipated increases in the hardness of the water supply.

Soap and Detergent Consumption. Communities that have hard water supplies and do not elect to provide softening nevertheless incur penalty costs in the form of higher expenditures for soap, synthetic detergents, and softening additives. Such costs are normally greater than would be incurred in a central softening treatment plant. In areas where portions of the population receive softened water and others do not, penalty costs incurred from hardness are the sum of two items: (1) the operation and maintenance of softening equipment for the portion of the population that benefits by such treatment, and (2) the additional cost of soap and detergents incurred by the remainder of the community.

Corrosion and Scaling of Metal Water Pipes and Fittings. The corrosiveness of water is governed by many factors such as temperature; presence of dissolved gasses, acids, and mineral salts; and electrochemical properties of the materials utilized. No simple relationship exists between the levels of mineral salts present and corrosiveness. Therefore, translation of such a relationship into tangible economic penalty costs is difficult and was not utilized in this study. Scaling, as evidenced in home hot-water systems such as water heaters, is also difficult to assess in terms of monetary values.

Accelerated Fabric Wear. Laundering with hard water has been stated to be a factor in the hastening of wear of clothing and other textile products. One reference(4) cites a 25-percent faster rate of wear with hard water than with soft. However, the relationship of fractional changes in hardness to fabric wear is difficult to quantify and, for this reason, penalty costs were not assessed for this factor.

Industrial

The effect of water quality on industrial uses is difficult to generalize because of the varied purposes to which industry puts water. A supply that meets Drinking Water Standards is often acceptable, but some industries require even better quality water. For example, the confectionery trade and certain paper-making and textile processes require water containing not over 200 parts per million (ppm) of dissolved solids and an iron content of 0.1 - 1.0 ppm. This is considerably better than domestic quality water.

Industrial water use may be classified by purpose as cooling, boiler feed, process, or general purpose. Data in a 1964 publication by the State of California Department of Water Resources(5) indicate that the relative magnitudes of these uses in California were: (1) cooling - 57 percent, (2) boiler feed - nine percent, (3) process - 25 percent, and (4) general purpose - nine percent. These relative percentages apply to the State of California as a whole and do not reflect the effects of recirculation of water which is quite significant in that state, especially for cooling and boiler feed operations.

When the raw water supply does not meet quality criteria for the various purposes described above, industry uses two general types of treatment approaches: external treatment or internal treatment. External treatment is used when better quality water is required for nearly every purpose for which water is to be used. Such methods include water softening, evaporation, and demineralization. Internal treatment, on the other hand, is used to improve quality for a particular purpose such as process water. This type of treatment includes such operations as chromate addition and chlorination in cooling systems for control of corrosion and slime. In some cases, economic considerations lead to a combination of the two treatment approaches.

Fundamental processes, water quality criteria, treatment methods, and associated penalty cost considerations for the four major industrial water uses are summarized in the following section.

Boiler Feed Water. Quality of boiler feed water is a significant factor in the (1) rate of scale formation on heating surfaces, (2) degree of corrosion to the system, and (3) quality of produced steam. Three quality parameters - total dissolved solids, alkalinity, and hardness - are most important, their relative significance being dependent upon the system's operating temperature and pressure.

For convenience and uniformity, the operating temperatures of systems are translated into equivalent pressures. Recommendations for quality requirements vary widely; one such recommendation is that of the American Boiler and Affiliated Industries shown in Table 1.

Table 1. American Boiler and Affiliated Industries' Limits for Boiler Water Quality Concentrations in Units with a Steam Drum[a]

Pressure at Outlet of Steam Generating Unit (lbs. per sq. in.)	Total Solids (ppm)	Total Alkalinity (ppm)	Suspended Solids (ppm)
0 - 300	3500	700	300
301 - 450	3000	600	250
451 - 600	2500	500	150
601 - 750	2000	400	100
751 - 900	1500	300	60
901 - 1000	1250	250	40
1001 - 1500	1000	200	20
1501 - 2000	750	150	10
2001 and higher	500	100	5

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a/ Nordel, Eskel, "Water Treatment for Industrial and Other Uses," Second Edition, Reinhold Publishing Corporation, New York, 1961, p. 273. (Reference No. 6)

Another recommendation for boiler feed water quality requirements was formulated by the Committee on Water Quality Tolerances for Industrial Uses, NEWWA as shown in Table 2.

Table 2. Suggested Limits of Tolerance for Boiler Feed Waters

(From Progress Report of the Committee on Water Quality Tolerances for Industrial Uses, NEWWA) (1959)

(units are in mg/l except as otherwise noted)

Pressure (psi)	0-150	150-250	250-400	Over 400
Turbidity	20	10	5	1
Color	80	40	5	2
Oxygen consumed	15	10	4	3
Dissolved oxygen**	2.0[a]	0.2[a]	0.0	0.0
Hydrogen sulfide*	5	3	0	0
Total hardness ($CaCO_3$)	80	40	10	2
Sulfate-carbonate ratio (ASME) ($Na_2SO_4:Na_2CO_3$)	1:1	2:1	3:1	3:1
Aluminum oxide	5	0.5	0.05	0.01
Silica	40	20	5	1
Bicarbonate**	50	30	5	0
Carbonate	200	100	40	20
Hydroxide	50	40	30	15
Total solids[b]	3000-500	2500-500	1500-100	50
pH value (Min.)	8.0	8.4	9.0	9.6

---

* Except when odor in live steam would be objectionable.

**Limits applicable only to feed water entering boiler, not to original water supply.

[a] Given as ml per liter. Multiply by 0.70 for ppm.

[b] Depends on design of boiler.

For the Project's analysis an operating tolerance of 3,500 mg/l was selected because: (1) most boilers in the Colorado River Basin appear to be operated in the lower pressure ranges, (2) the American Boiler Manufacturer's Association stipulates a limit of 3,500 mg/l for boilers operating at 300 psi or less in its standard guarantee of steam purity[1], and (3) the relatively high tolerance provided a somewhat conservative estimate of boiler feed water penalties.

---

[1] Betz Handbook of Industrial Water Conditioning, Betz Laboratories, Inc., Philadelphia, 1962, p. 211. (Reference No. 7)

For highly mineralized water supplies, some form of softening is mandatory before use as a boiler feed water. While the costs of water softening are generally proportional to the amount of hardness removed, the cost of evaporation to produce distilled water is essentially independent of the level of mineral constituents in the raw water supply. For units operating at pressure levels where boiler feed water softening by more conventional means is appropriate, the penalty costs due to salinity increases can be partially assessed in terms of increased treatment costs. Such an approach is less readily applicable to high-pressure boilers since the cost of obtaining the necessary quality by distillation or evaporation has little or no dependence on influent quality. Raw water quality may, however, affect the cost of pre-treatment before evaporation.

In order to maintain a level of total dissolved solids in the boiler system that can be tolerated, some of the concentrated boiler water must be removed from the system. This process of solids removal by either continually or intermittently drawing off a portion of the circulating water is known as "blowdown." The quality of the boiler feed water introduced to the system in relation to the concentration that can be tolerated within the system determines the amount of blowdown required.

Cooling Water. Cooling water is used for a variety of purposes, including the cooling of condensers, internal combustion engines, and compressors. Also included would be water used in air conditioners as well as a variety of other cooling processes.

Although the intake water quality requirements and the extent of water treatment depend in large measure on the particular system employed, there are some generally desirable characteristics of an intake water. The following characteristics are of great significance: low, relatively constant temperature; non-corrosiveness; non-slime forming; non-scaling. The following specific limits on the concentration of quality parameters are presented in the manual, "Water Quality and Treatment."(8)

Turbidity	50 mg/l
Hardness	50 mg/l
Iron	0.5 mg/l
Manganese	0.5 mg/l
Iron and Manganese	0.5 mg/l

Information on industrial cooling water practice available to the Project indicates that, within the Lower Colorado and Southern California areas, the concentration of total dissolved solids in cooling water systems is normally held at a level of 2,000 mg/l. In addition, the publication, "Water Quality Criteria,"(2) states:

> "Among the constituents of natural water that may prove detrimental to its use for cooling purposes are hardness, suspended solids, dissolved gasses, acids, oil, and other organic compounds and slime-forming organisms."

Although cooling water systems are subject to the same type of problems that affect boiler water systems (e.g., scale formation and corrosion), each type of system experiences those problems to a different degree. Once-through systems have fewer scale-buildup problems than either open-recirculating or closed-recirculating systems. A closed system utilizes a heat-exchanging mechanism rather than an evaporative device such as a cooling tower to remove excess heat in the system. Corrosion problems in open-recirculating systems are particularly acute due to the continuous saturation of circulating water with oxygen upon passage through the cooling tower.

Penalty costs for quality degradation are incurred in additional treatment costs and greater makeup water requirements. Calcium carbonate scaling is often controlled by anti-nucleating agents which increase the solubility of calcium carbonate. The use of such agents is limited insofar as it is necessary to limit the mineral concentration by means of blowdown. Often the relative costs of makeup water and treatment methods dictate the magnitude of blowdown. Corrosion prevention is frequently accomplished by corrosion inhibitors like polyphosphates.

Process Water. Process water is used in preparation of the products of industry. This water is either incorporated directly in the finished product, such as in bottled beverages and canned foods, or used in transporting, washing, mixing, dissolving, concentrating, or cooking operations. As might be expected, the water quality requirements vary widely according to type of use and, in some instances as previously noted, they are more exacting than for domestic water supply. In such cases the expense of treating a public water supply to conform to particular industrial needs is accepted as a normal business expense. In view of the great variety of special qualities needed in industrial process waters, it is not feasible to make a comprehensive penalty cost analysis. However, a summary of the water quality tolerance for industrial process water uses is shown in Table 3.

General Purpose Water. General purpose water is used by industry for plant personnel needs (drinking water, sanitation), general cleaning, lawn sprinkling, and fire protection. While drinking water can be

Table 3. Water Quality Tolerance for Industrial Process Uses[a]
(Allowable limits in parts per million)

Industry or Use	Turbidity	Color	Hardness as $CaCO_3$	Iron[b] as Fe	Manganese as Mn	Total Solids	Alkalinity as $CaCO_3$	Odor Taste	Hydrogen Sulfide	Other Requirements[c]
Baking	10	10		0.2	0.2			Low	0.2	P.
Brewing										
Light Beer	10			0.1	0.1	500	75	Low	0.2	P. NaCl less than 275 ppm (pH 6.5 - 7.0)
Dark Beer	10			0.1	0.1	1,000	150	Low	0.2	P. NaCl less than 275 ppm (pH 7.0 or more)
Canning										
Legumes	10		25-72	0.2	0.2			Low	1	P.
General	10			0.2	0.2			Low	1	P.
Carbonated Beverages	2	10	250	0.2	0.2	850	50-100	Low	0.2	P. Organic color plus oxygen consumed less than 10 ppm
Confectionery				0.2	0.2	100		Low	0.2	P. pH above 7.0 for hard candy
Food: General	10			0.2	0.2			Low		P.
Ice	5	5	50	0.2	0.2			Low		P. SiO_2 less than 10 ppm
Laundering			50	0.2	0.2					
Plastics, clear, uncolored	2	2		0.02	200.0	200				
Paper and Pulp										
Groundwood	50	20	180	1.0	0.5					No grit, corrosiveness
Kraft Pulp	25	15	100	0.2	0.1	300				
Soda and Sulfide	15	10	100	0.1	0.05	200				
High-grade Light Papers	5	5	50	0.1	0.05	200				
Rayon (Vicose)										
Pulp Production	5	5	8	0.05	0.03	100	Total 50; Hydroxide 8			Al_2O_3 less than 8 ppm, SiO_2 less than 25 ppm, Cu less than 5 ppm
Manufacture	0.3		55	0.0	0.0					pH 7.8 to 8.3

Table 3. Contd. Water Quality Tolerance for Industrial Process Uses[a]
(Allowable limits in parts per million)

Industry or Use	Turbidity	Color	Hardness as $CaCO_3$	Iron[b] as Fe	Manganese as Mn	Total Solids	Alkalinity as $CaCO_3$	Odor Taste	Hydrogen Sulfide	Other Requirements[c]
Tanning	20	10-100	50-135	0.2	0.2		Total 135; Hydroxide 8			
Textiles: General	5	20		0.25	0.25					
Dyeing	5	5-20		0.25	0.25	200				Constant composition Residual alumina less than 0.5 ppm
Wool Scouring		70		1.0	1.0					
Cotton Bandage	5	5		0.2	0.2			Low		

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[a] Anonymous, "Progress Report of Committee on Quality Tolerance of Water for Industrial Uses," Journal New England Water Works Association, Volume 54, 1940, p. 271. (Reference No. 9)

[b] Limit given applies to both iron alone and the sum of iron and manganese.

[c] "P" indicates that potable water conforming to U. S. Public Health Service standards is necessary.

impaired or rendered unusable by high salinity concentrations, the quantity involved, in comparison to that used elsewhere in the industrial plant, is so small that any penalty costs associated with salinity increases would not be significant.

Hot wash water, which is used in lavatories and plant laundries, may need to be softened but the same penalty cost considerations apply as for municipal and domestic water previously discussed and the quantity of water involved is comparatively insignificant. Increases in salinity and hardness have little effect on water used for general cleaning, lawn sprinkling, and fire protection.

Irrigation

Several characteristics of water are important in relation to its use as an irrigation supply. These characteristics include: (1) the total concentration of soluble salts, (2) the relative proportion of sodium to other cations, (3) the concentrations of boron or other toxic elements, and (4) under certain conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium. A discussion of each of these characteristics follows and is based on Handbook 60(10) of the U. S. Department of Agriculture, unless otherwise indicated.

The concentration of soluble salts in irrigation water is expressed either in terms of specific electrical conductance, which is a measure of concentration of ions per unit of water, or in terms of total dissolved solids, in milligrams per liter of water. The main adverse effect of a high salt content in irrigation water is in reducing osmotic action, and thereby reducing the uptake of water by plants. Some other effects involve the direct chemical effects upon metabolic reactions of plants (toxic effects), and the indirect effects of changes in soil structure, permeability, and aeration.(11)

It is difficult to set precise salinity limits for irrigation water for several reasons, including: (1) plants vary widely in their tolerance to salinity and to specific constituents, (2) soil types, climate conditions, and irrigation practices influence the reactions of a crop to salt constituents, and (3) the interrelationships between constituents may be highly significant. Although absolute limits cannot be set for irrigation water, the U. S. Department of Agriculture's Salinity Laboratory has established some general classifications which are shown in Table 4.

Table 4. Classification of Irrigation Water as to Salinity Hazard

Classification	Conductivity micromhos/cm
Low	100 - 250
Medium	250 - 750
High	750 - 2250
Very High	> 2250

Salts dissolved in irrigation water tend to accumulate in the soil on which they are applied. This accumulation eventually causes the soil to become too saline to support plant life. Therefore, in order to maintain productivity, excess water must be applied to wash out an amount of salt equal to the amount contained in the applied water. The application of excess water, termed the leaching requirement, is directed at maintaining a salt balance within the plant root zone.

In humid climates, leaching is accomplished by the excess of percolating rain and snow-water. In arid climates there is no such natural excess, and the leaching must be accomplished by application of irrigation water in excess of the normal crop growth requirements.

The amount of irrigation water needed for leaching increases in proportion to the salinity concentration of the applied irrigation water. Any increase in the salinity of an irrigation water supply therefore results in an economic penalty since more water is required for equivalent service. This is a large, although sometimes unrecognized, economic loss caused by degraded irrigation water.

Combating the effects of saline irrigation water by leaching assumes that the soil will accept an increase in the amount of irrigation water applied. For the porous soils of the arid or semi-arid areas of the Southwest, this assumption is generally valid.

There are two alternative courses an irrigation water user may follow when confronted with degradation in the quality of his water supply: (1) apply more water to the fields and thereby maintain crop yields, or (2) maintain present water use and thereby suffer a decrease in crop yields. Obviously, there are disadvantages in doing either.

If additional water necessary for leaching is not available, the irrigator will have to either: (1) irrigate the same acreage and suffer a decrease in crop yields, or (2) take some acreage out of production and use the water previously applied to this acreage to leach the remaining acreage in order to maintain crop yields. Either alternative results in an economic loss to the water user, comparable to that suffered when additional water is available for leaching.

Where additional water is available for leaching several other associated economic detriments are incurred. As the applied irrigation water becomes more saline, greater and greater volumes of water are needed for leaching to maintain the salt concentration in the plant root zone at a satisfactory level. In some areas, the application of greater volumes of water may make it necessary to install artificial drainage facilities, such as open drains or buried tile drains. Such drainage facilities can represent a substantial cost to the irrigator.

Water percolating through the plant root zone will remove applied fertilizers as well as mineral salts. The nitrate fertilizers are especially susceptible to loss this way because of their high solubility. As additional water is applied for leaching, an additional amount of fertilizer must be applied to the land to offset the loss of fertilizer dissolved by the additional leaching water.

Finally, when additional water has to be applied for leaching purposes, more frequent applications of water are normally required causing increased labor costs.

The second characteristic of irrigation water that must be considered is the relative proportion of sodium to other cations. The alkali hazard involved in using irrigation water is determined by the absolute and relative concentrations of cations in the water. Soluble inorganic constituents in irrigation water react with soils as ions rather than as molecules. Calcium and magnesium in proper proportions maintain soil in good condition of tilth and permeability. The opposite is true if sodium predominates. In the soils of arid and semi-arid regions, calcium and magnesium are the major cations held in the soil in exchange form. Under normal use these soils have a favorable physical condition for root and water percolation. In situations where sodium is predominant, the soil pores begin to seal resulting in a decrease in permeability.

It is easier for calcium to replace sodium in the exchange complex than vice versa. Unless the sodium of the soil solution is in considerable excess of the calcium no reaction will occur. The soil solution is always more concentrated than the applied irrigation water. If the amount of magnesium is high in proportion to the total replaceable cations of the soil, more sodium will be absorbed than if calcium is the only divalent cation present.

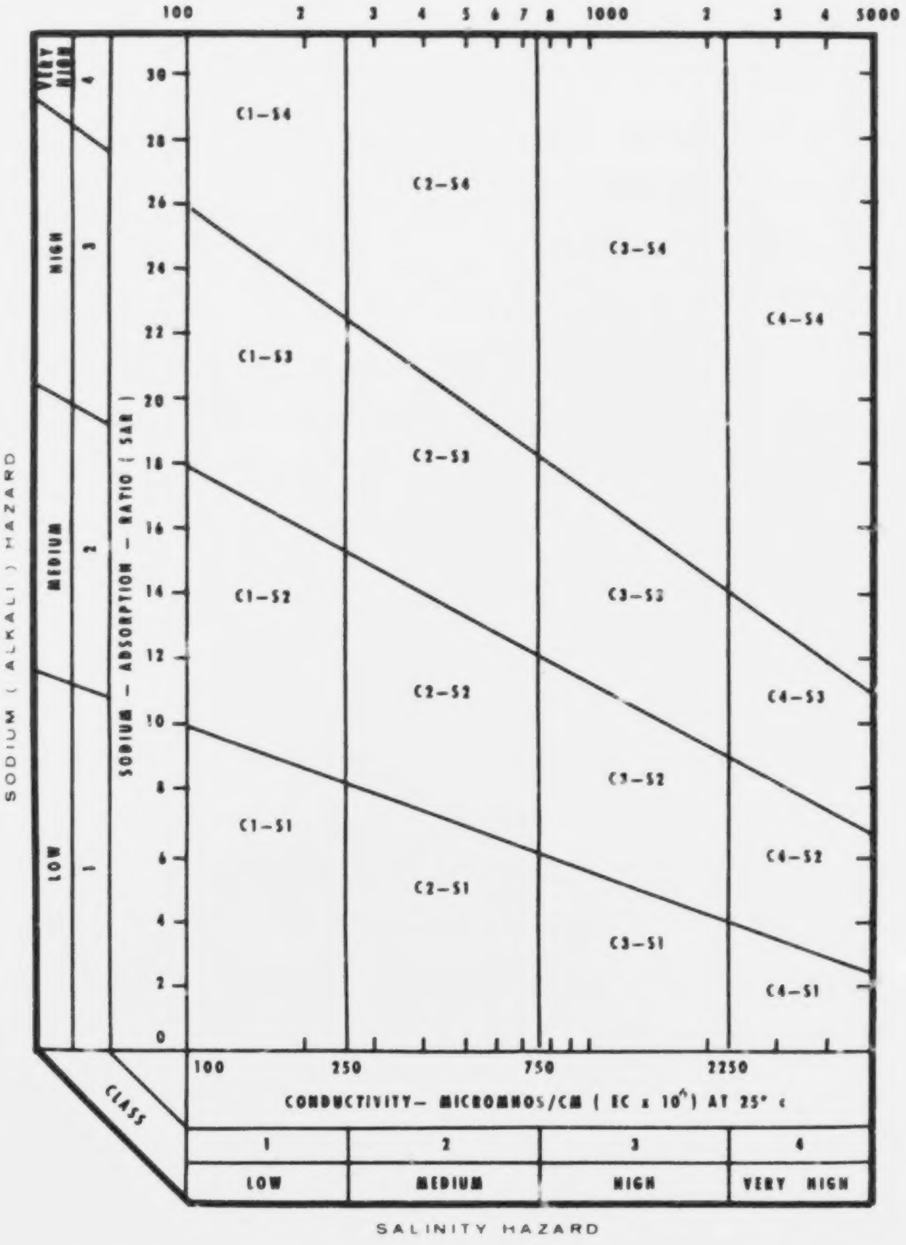
The sodium adsorption ratio (SAR) has been developed to express the sodium hazard in irrigation water. The ratio expresses the relative activity of sodium ions in the exchange reaction with ions in the soil. The ratio is defined by the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{++} + Mg^{++})}{2}}}$$

where Na^{+}, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter of the respective ions. The SAR, in other words, is related to the adsorption of sodium by the soil.

The Salinity Laboratory has set up classifications of irrigation water in regard to the sodium hazard. The sodium hazard varies with the salinity concentration of the irrigation water. The classifications are shown in Figure 1.

Low sodium water can be used without much danger of development of harmful levels of sodium. However, some sodium sensitive crops such as stone fruit trees and avocados may be injured. An appreciable sodium hazard may develop in fine textured soils with the use of medium sodium



Note Reproduction from U. S. Department of Agriculture, U. S. Salinity Laboratory, "Saline and Alkali Soils," Agriculture Handbook No. 60, 1954, Figure 25(10)

Figure 1. Diagram for the Classification of Irrigation Waters

water, especially under low leaching conditions. The presence of gypsum in the soil is helpful. High sodium water may produce harmful effects in most soils and will require special soil management such as good drainage, high leaching, and addition of organic matter. A very high sodium water is generally not satisfactory for irrigation except at low or medium salinity concentrations, where the solution of calcium from the soil or the use of gypsum or other additives make the use of such water feasible.

A third characteristic of irrigation water that must be considered is the boron concentration. This element is present in most natural waters with concentrations varying from traces to several milligrams per liter. Boron is essential to plant growth but is very toxic at concentrations only slightly above optimum. Eaton[1] found that many plants made normal growth in sand cultures with a trace of boron, but injury often occurred with cultures containing one mg/l.

In waters containing high concentrations of bicarbonate ion, as the soil solution becomes more concentrated there is a greater tendency for calcium and magnesium to precipitate as carbonates. This reaction does not usually go to completion, but it may go far enough to cause a decrease in the concentrations of calcium and magnesium with an increase in the relative proportion of sodium.

Eaton's work[2] resulted further in classification of waters with regard to the bicarbonate ion hazard using the "residual sodium carbonate" concept. This classification is shown in Table 5. Waters classified as marginal may be used if good management is practiced.

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[1] Eaton, F. M., "Deficiency, Toxicity and Accumulation of Boron in Plants," Journal Agricultural Research, Volume 69, Illustration 1944, pp. 237-277. (Reference No. 12)

[2] Eaton, F. M., "Significance of Carbonates in Irrigation Waters," Soil Science, Volume 69, 1950, pp. 123-133. (Reference No. 13)

In appraising the quality of irrigation water, the salinity hazard should be considered first, followed by the alkali hazard. Next, consideration should be given to boron or other possible toxic elements, followed by consideration of the bicarbonate ion concentration.

Table 5. Classification of Irrigation Water as to Bicarbonate Ion Hazard

Classification	Residual sodium carbonate in milliequivalents
Probably safe	< 1.25
Marginal	1.25 - 2.5
Not suitable	> 2.5

Livestock

Information on livestock tolerance to mineralized water was dervied from the "Report of the Committee on Water Quality Criteria" published by the Federal Water Pollution Control Administration, U. S. Department of the Interior.(14) The following discussion of the effect of total dissolved solids on livestock is also based on "Water Quality Criteria"(2) published by the California Water Quality Control Board.

It has been assumed that water safe for human use is also safe for livestock, and it has been recommended that such water be used for best stock production. However, it appears that stock animals have higher tolerances than humans, although they may differ in tolerance to particular substances. The use of highly mineralized water may result in physiological disturbances such as gastrointestinal symptoms and death. In animals, lactation and reproduction can be affected by use of water of high concentrations of unfavorable minerals. Milk and egg production also may be reduced or interrupted. Animals can adjust, within limits, to consumption of saline water that at first they refuse to drink. However, a sudden change from good water to highly saline water can cause acute salt poisoning and rapid death. The salt tolerance of an animal depends upon several factors including species, age, physiological condition, season of the year, diet, and the quality and quantity of salts present. Officials of the Department of Agriculture and the government chemical laboratories of Western Australia have established threshold concentrations for livestock water in Western Australia as shown in Table 6.

The effect of water containing heavy concentrations of chlorides, sulfates, carbonates, bicarbonates, sodium, calcium, and/or magnesium is due to the total salts present rather than the toxic effect of any one constituent. Alkali salts are more harmful than neutral salts, sulfates more harmful than chlorides, and magnesium chloride more harmful than calcium or sodium chloride. Some of the states have set classifications for stock water, as shown in Table 7. Except for short reaches of some tributary streams, the waters of the Colorado River Basin would fall within the highest quality classification.

Some particular salts are toxic to animals, even in very low concentrations. Compounds causing trouble in water are fluorides, nitrates, and salts of selenium and molybdenum. The effect of fluoride on animals is similar to that for humans, and 1.0 mg/l is the threshold value below which no harm results. Nitrates in livestock water have been harmful in lower concentrations than mixtures of chlorides and sulfates of alkaline metals. When the salinity concentration of livestock water

Table 6. Safe Upper Limits of Salinity Concentrations Recommended for Livestock Water in Western Australia

Animal	Threshold Salinity Concentration in mg/l
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle, dairy	7,150
Cattle, beef	10,000
Adult dry sheep	12,900

Table 7. Salinity Classifications for Livestock Water Set by Several States

State	Classification and Concentration in mg/l			
Montana	good 0-2500	fair 2500-3500	poor 3500-4500	unfit > 4500
South Dakota	excellent 0-1000	good 1000-4000	satisfactory 4000-7000	unsatisfactory > 7000
Colorado	acceptable 0-2500	--	--	--

exceeds 570 to 1,000 mg/l, the nitrate concentration should be watched carefully. The principal hazard of molybdenum and selenium results from its uptake in pasture grasses and concentration in the plant tissues. If copper is fed to cattle in some form along with molybdenum, the toxicity of the molybdenum appears to be reduced. The concentration of these minor elements in waters of the Colorado River and tributaries are generally below the threshold values. In recent years the fluoride concentrations at two stations on the Gila River were well above the threshold value, being as high as 4.2 mg/l. These two stations are the Gila River below Gillespie Dam and the Gila River at Kelvin, Arizona.

NON-CONSUMPTIVE USES

Non-consumptive uses of water include hydroelectric power generation, navigation, water-oriented recreation, fish and wildlife, silt control, general water quality control, and ground water recharge. Detriments to navigation and power generation certainly should be insignificant for the projected rise in salinity (from about 800 to 1,200 parts per million at Imperial Dam). Similarly, little or no detrimental effect can be envisaged on native fauna, water sports, recreation and esthetic enjoyment. Although minor detrimental effects are expected for two categories of non-consumptive use--(1) fish and wildlife, and (2) ground water recharge--these effects are not expected to have significant economic impact on the Basin for the anticipated range of salinity concentrations.

Fish and Aquatic Life

Fish and aquatic life are affected by dissolved substances in two basic ways:

(1) Substances such as aluminum, iron, manganese, zinc, and copper can be toxic to some species of fish in very low concentrations;

(2) Other substances exert lethal osmotic pressures at high concentrations. A pure solution of NaCl is lethal to fresh-water fish at concentrations in excess of 7,000 ppm, the concentration at which the fish's osmotic blood pressure (six atmospheres) is exceeded.

Criteria for the required quality of fresh water supply that will support a good mixed fish population were developed by Ellis, who proposed the following limits:(15)

1. Dissolved oxygen, not less than 5 mg/l;
2. pH, approximately 6.7 to 8.6, with an extreme range of 6.3 to 9.0;
3. Specific conductance at 25° C, 150 to 500 mho X 10^{-6}, with a maximum of 1,000 to 2,000 mho X 10^{-6} permissible for streams in western alkaline areas;
4. Free carbon dioxide, not over 3 cc per liter;
5. Ammonia, not over 1.5 mg/l;
6. Suspended solids such that the millionth intensity level for light penetration will not be less than 5 meters.

In the absence of toxic substances or pollutants, the water described above is favorable, not merely sublethal, for a mixed warm-water fish population and its food organisms. It must not, however, be assumed that fish are not found or cannot survive in waters with concentrations beyond these limits.

Measures of total dissolved solids, whether in terms of parts per million, conductivity, or osmotic pressure equivalents, are inadequate as an index of toxicity. Therefore, biossay techniques are used to determine the degree of dilution essential for the safe disposal of brines and other complex wastes which are high in dissolved solids.

After a review of available biological data and a limited amount of field investigations, it can be concluded that the expected future increases in salinity per se within the Colorado River Basin will have very little or no effect on the fish and aquatic life. However, the Salton Sea of Southern California, whose inflow is originally derived from the Colorado River, is facing possible extinction to its fish and aquatic life if present trends in salinity increases prevail into the future. Present salinity of the sea is about 33,000 mg/l, or nearly that of sea water. Chloride concentrations approximate 14,000 mg/l. It has been estimated(16) that salinity will increase about 400 mg/l per year. Other researchers have indicated that salinity can be expected to increase at more rapid rates. At the rate of 400 mg/l per year the salinity of the sea will reach 40,000 mg/l in 1975 and 50,000 mg/l in the year 2000. While the total effects of such salinity levels on the biota of the sea is not definitely known, the State of California Department of Fish and Game believe that the food chain will be seriously affected and possibly destroyed sometime around 1980-1990. The problems of the Salton Sea and possible solutions are currently being considered by several groups.

Ground Water Recharge

Underground basins are a major source of water supply in three of the seven Colorado River Basin states. The ground water supply proportion of the total water supply in the States of Arizona, California, and New Mexico is 69 percent, 36 percent, and 58 percent, respectively. In Southern California ground water comprises about 50 percent of the total supply, or approximately 1,400,000 acre-feet per year, and 300,000 to 400,000 acre-feet of this amount is in excess of the estimated safe yield from natural recharge.

Imported water has a large and growing role in the replenishment of ground water basins in Southern California. This replenishment is the intentional or managed recharge, and not the adventitious recharge accomplished by disposal of waste water on land. The amount of Colorado River water used for direct recharge of ground water basins in Los Angeles and Orange counties was 346,000 acre-feet in 1962-63 and 300,000 acre-feet in 1963-64. The use of Colorado River water for this purpose is declining because of the growing demand for domestic and industrial water. Leading authorities in the water resources management field in California foresee a continual decline in the amount of Colorado River water available for recharge. If and when the Central Arizona Project is completed, Colorado River water will probably not be available for direct recharge in California because all of the Metropolitan Water District entitlement will be needed for municipal and industrial uses.

The Central Arizona Project planning documents indicate that imported Colorado River water will not be used for direct replenishment. It is anticipated that the Project will provide a net delivery of

1,020,000 acre-feet annually. Municipal and industrial users will consume approximately 250,000 acre-feet of this net delivery, and the remainder will be used for supplemental irrigation. A fraction of this amount will certainly replenish ground water basins by percolation, but this fraction will contain nearly all of the dissolved salts in the imported water, plus increments added in a cycle of municipal, industrial or agricultural use.

The effects of the quality of recharge water upon a ground water body have been recognized only in recent years. In the operation of any ground water reservoir large amounts of mineral salts may be brought in by tributary inflow; both surface and underground. As a result of human activities other salts are brought into the area in the form of agricultural chemicals, inorganic fertilizers, and numerous chemicals of commerce. A considerable portion of these latter forms of salt may percolate through the upper soil horizon to the ground water.

Since the ground water body is of finite size, it is evident that a stable condition of quality requires salts to be removed in the same amount that enter the Basin. This condition is known as salt balance. In nature it is achieved by removal of the dissolved salts in subsurface outflow or in rising ground water (springs) which contribute to surface streams. In developed areas the process may be modified considerably by well pumping, import or export of water, outfall sewers, etc., but the principle is unchanged.

The process can be expressed mathematically for an idealized case by the simple relation,

$$\frac{dx}{dt} = I - O$$

where x = the total weight of dissolved salts in a ground water basin at any time _t_,

I = the rate of inflow or addition of salts

O = rate of outflow of salts.

If the natural balance is altered by the importation of water containing dissolved mineral salts, the outflow of salts must be increased; otherwise, water quality will deteriorate. The increased burden of salts can be removed in three ways: (1) by an increased outflow of water of unchanged salinity concentration, (2) by an unchanged outflow of water with an increased proportion of dissolved salts, or (3) by some condition intermediate between these two.

If the quality of the imported water becomes degraded in time, i.e. attains a higher salinity, it is apparent that provision must be made for removal of the new burden of salt. A degradation of the imported source engenders two alternative economic penalties. Either more water must be wasted in outflow from the Basin in order to maintain a stable water quality in the underground aquifers, or the salt concentration in those aquifers will build up, perhaps to the point where the ground water will become unfit for domestic, industry or agriculture uses. This is an issue in the proposed Central Arizona Project. A worsening of the mineral quality of Colorado River water might generate these undesirable effects: (1) the need for higher outflow, with consequent waste of water and drainage expense, and (2) a salinity increase in the ground water basins in the Project area.

Specific limits on the quality of water for ground water recharge have rarely been recommended or imposed by regulatory agencies. Numerous factors must be taken into consideration in the establishment of such limits including: (1) the quality of the recharge waters, (2) a reasonable allowance for effects of water use in their area of origin, (3) the existing quality of water in the aquifers to be replenished, and (4) the beneficial uses of water within the overlying areas.

In the late 1950's a State of California regulatory agency(17) established mineral quality objectives for the underground and surface water outflows in the Bunker Hill Basin and in the Santa Ana River. These objectives were designed to preserve the quality of those waters for replenishment of downstream ground water basins. The limiting values adopted are shown in Table 8.

In 1955 a board of consultants to the California Department of Water Resources recommended chemical and physical quality standards for water which was to be exported from the Sacramento-San Joaquin Delta to Southern California.(18) Major uses of the exported water included ground water replenishment, which was undoubtedly an influential factor in determining the quality limits which are shown in Table 9.

The results of a water resources study(19) made several years ago by the Department of Water Resources of the State of California illustrate the importance water quality may have in ground water recharge. An analysis was made of the effects of differences in quality between two alternative replenishment supplies for certain ground water basins in Riverside and San Bernardino Counties. The economic penalty incurred by using the poorer of the two sources was estimated to be about four million dollars annually.

Table 8. Proposed Ground Water Quality Objectives for the Bunker Hill Basin and the Santa Ana River in California

Constituent	Maximum Tolerable Concentration (parts per million) Bunker Hill Unit	 Santa Ana River at Prado
Total dissolved solids	500	800
Total hardness as $CaCO_3$	300	400
Chloride	60	175
Bicarbonate	300	320

Table 9. Recommended Chemical and Physical Quality Standards for Water to be Exported to Southern California from the Sacramento-San Joaquin Delta

Item	Limit
Total dissolved solids	400 ppm
Electrical conductance @ 25° C	600 micromhos
Hardness as $CaCO_3$	160 ppm
Sodium percentage	50%
Sulphate	100 ppm
Chloride	100 ppm
Fluoride	1.0 ppm
Boron	0.5 ppm
pH	7.0 - 8.5
Color	10 ppm

The actions cited above serve to show that salinity or mineral quality is an important consideration in waters used to replenish ground water reservoirs, and that poor quality of such recharge waters is likely to engender economic loss. Although methods can be derived to evaluate such losses, data for such an evaluation are quite limited. Therefore, no attempt was made to evaluate such effects in the Project's salinity studies of the Colorado River Basin.

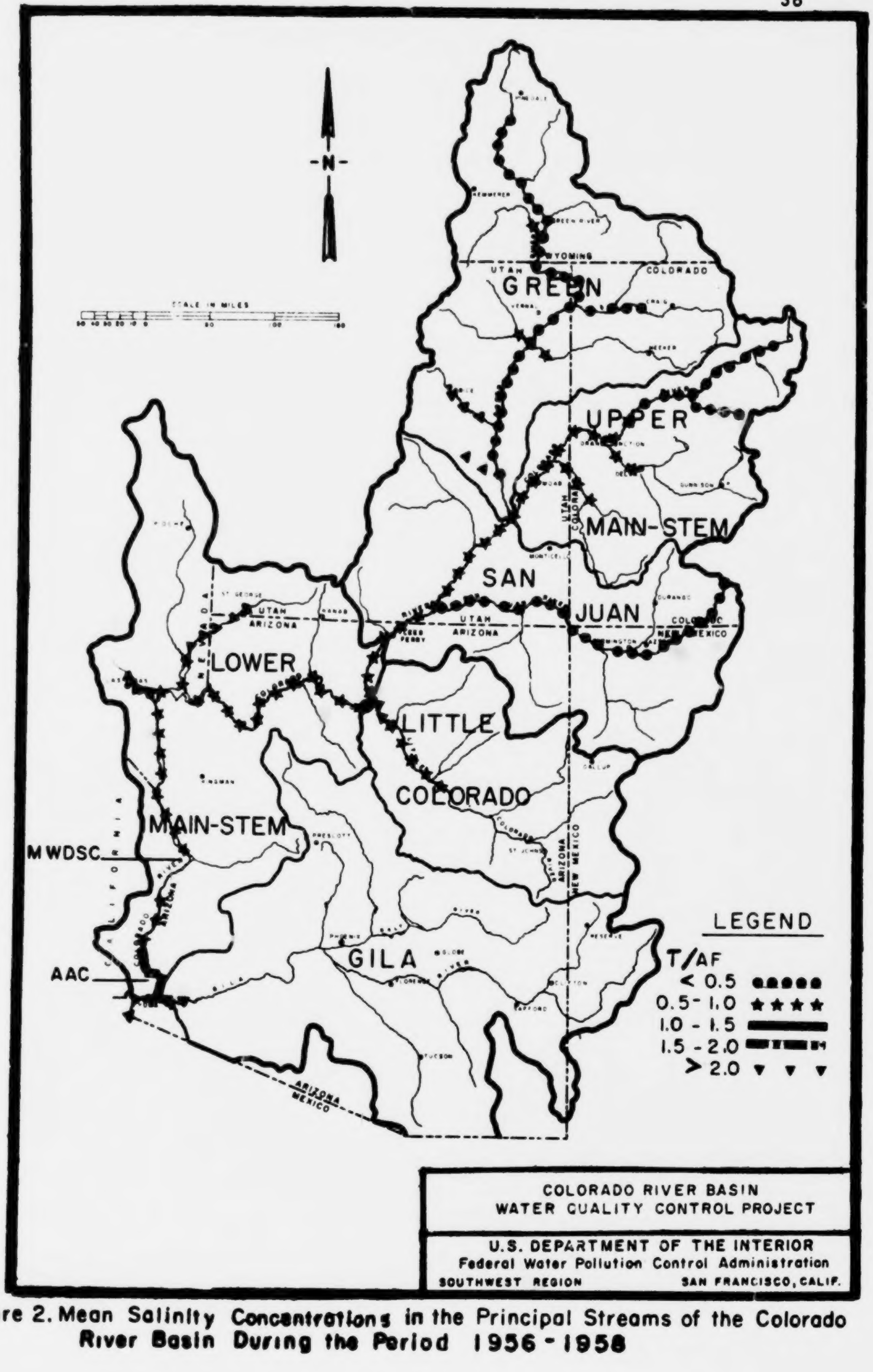
CHAPTER III. PRESENT AND FUTURE MINERAL QUALITY

PRESENT MINERAL QUALITY

The findings of field studies conducted by the Project to define present mineral quality and its causes are presented in Appendix A of the Project's Report entitled "Mineral Water Quality Problem in the Colorado River Basin." The purpose of this section is to summarize those findings and to relate them to methods used in the economic impact analysis

A summary of water quality, as defined by Project field studies during the period October, 1963, to May, 1966, is shown in Figures 19 through 46 of Appendix A. Although the overall findings of the Project studies were substantially identical to the 1956-1958 quality described above, local discrepancies were noted. Discrepancies of this type are quite common when two records based upon relatively short-duration studies are compared The value of short-term studies resides in refinement of cause-and-effect relationships; however, long-term records and analysis must be used to establish average or base qualities.

Average salinity concentrations existing in the Basin streams during the period from 1956 to 1958 are illustrated by Figure 2 Salinity increases progressively in the main stem of the Colorado from the headwaters to the mouth. With the exception of a few streams such as the Price, San Rafael and Dolores Rivers, mineral quality of major streams in the Upper Basin (upstream from Lees Ferry) is good, averaging less than 1 0 tons of dissolved solids per acre foot (T/AF). In the Lower Basin salinity increases more rapidly, reaching concentrations


N
SCALE IN MILES
WYOMING
UTAH
COLORADO
GREEN
UPPER
MAIN-STEM
SAN
JUAN
UTAH
ARIZONA
COLORADO
NEW MEXICO
LOWER
LITTLE
COLORADO
MAIN-STEM
MWDSC
CALIFORNIA
ARIZONA
NEW MEXICO
GILA
AAC
ARIZONA
MEXICO
LEGEND
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< 0.5 ●●●●●
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1.0 - 1.5
1.5 - 2.0
> 2.0 ▼ ▼ ▼
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF.

Figure 2. Mean Salinity Concentrations in the Principal Streams of the Colorado River Basin During the Period 1956 - 1958

exceeding 2.0 T/AF at the Mexican border. Diverse factors, both natural and man-caused, contribute to this pattern of mineral quality as described elsewhere in this report

As discussed later in this chapter, a suitable salinity base was established to which a comparison of projected quality was made. Since any record of water quality is a function of changing patterns of water use and pollution discharge, it was determined that a mathematical model of the Basin should be constructed to similate long-term mineral quality The development of the model and the resulting analyses are described in the section of this chapter entitled, "Methods and Assumptions Used to Project Mineral Quality " Results of the analyses based upon the 1942-1961 hydrologic period are summarized in Table 10. These results, corrected for 1960 condition of water use, are referred to as present, or 1960, mineral water quality in the remainder of the report

AREAS AFFECTED BY MINERAL QUALITY

The greatest impact of mineral quality occurs in the Lower Colorado Basin and Southern California water service area where water usage is much greater than in the Upper Basin The relative concentration of population and irrigation water demands in the Upper and Lower Basins are shown in Table 11 It is clear that there is a preponderance of population and irrigation in the Lower Basin and, consequently, a greater requirement for water The areas of greatest water use, or the location of largest water-demand centers, are below Lees Ferry and comprise the subbasins of the Lower Main Stem (LMS) of the Colorado with urban territory centered in Las Vegas and Yuma; the Gila Basin,

Table 10. Total Dissolved Solids Concentrations in the Colorado River at Selected Stations (1960)

Stream Mile (Measured from Southern International Boundary)	Station	Total Dissolved Solids[a/] (Mg/1)
716	Lee Ferry, Arizona	558
625	Grand Canyon	631
356	Hoover Dam	697
200	Parker Dam	684
50	Imperial Dam	759
28	Yuma, Arizona	2,632[b/]

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a/ Results of flow and salt routing model based on 1942-1961 hydrologic period.

b/ Time-weighted mean value for water year 1962, including drainage from Wellton-Mohawk Project.

Table 11. Population and Irrigation Water Use in the Colorado River Basin and Southern California Water Service Area

Area	1960 Population (1000)	Estimated Deliveries of Water for Irrigation (acre-feet per year)
Upper Basin above Lee Ferry	338	2,800,000[a]
Lower Basin below Lee Ferry		
Little Colorado Subbasin	106	--
Gila Subbasin	1,159	--
Lower Main Stem Subbasin less Imperial County, California	236	--
Southern California Water Service Area	8,900[b]	--
Lower Basin plus Southern California Water Service Area	10,401	6,323,000[c]
Percent of Total in Upper Basin	3	31
Percent of Total in Lower Basin and Southern California	97	69

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[a] Based upon an assumed 60 percent irrigation efficiency, a high value, and a total estimated consumptive use of 1,685,000 acre-feet. See report of the U. S. Department of the Interior, "Quality of Water, Colorado River Basin," January 1965, pp. 10-11. (Reference No. 20)

[b] Comprises the 1963 population of the Metropolitan Water District plus appropriate parts of Imperial County.

[c] Comprises 4,690,000 acre-feet in Lower Basin plus 1,633,000 acre-feet in the Southern California Water Service Area. See Table 8 of U. S. Department of the Interior report, "Pacific Southwest Water Plan," August 1963. (Reference No. 21)

with large populations in Phoenix and Tucson; and the Southern California (SC) water service area. The latter area covers all of Southern California lying outside the natural drainage basin of the Colorado River which is served by water exported from that stream. It includes parts of Los Angeles and San Diego served by the Metropolitan Water District (MWD) of Southern California and the Imperial and Coachella Valley lands and communities which receive water via the All American Canal.

Present use of Colorado River water in Arizona is limited to land riparian to, or located only a short distance from the river. The principal users are the Colorado River Indian Reservation (CRIR) with consumptive water use in 1960 of about 185,000 A.F. and the several subdivisions of the Gila and Yuma Projects with consumptive water use in 1960 of about 640,000 A.F.(22) The only sizeable diversion for urban use is for the city of Yuma, which currently uses about 8,000 A.F. per year. The Pacific Southwest Water Plan of the Department of the Interior provides for considerable expansion of irrigation on the CRIR, with a future water requirement estimated to reach 380,000 A.F. annually by the year 2000(21). These areas are all sensitive to changes in mineral quality of water at the present time.

The Central Arizona Project (CAP) of the Department of the Interior will, when completed (probably about 1979), divert a gross volume of about 1,600,000 A.F. annually from the Colorado River at Lake Havasu. This diversion will be decreased to 676,000 A.F. annually by the year 2030. Delivery to municipal and industrial users in Phoenix and Tucson will make up five percent of the diversion and is expected to increase to 50 percent in 2030. The remainder of the delivery will be for agricultural service in the rural areas of Maricopa and Pinal Counties.(23) These uses, as well as the replenishment of ground water bodies in the area, will be affected by changes in mineral quality of the Colorado River supply after 1975 and the associated importation of over one million tons of salt annually.

Although the principal effects of future degradation in mineral quality will be experienced in the Lower Basin, two Upper Basin areas will experience pronounced salinity increases in surface water supplies because of future economic and water resources developments. These are the Duchesne Basin in Utah and the upper basin of the San Juan River above Shiprock, New Mexico.

The first, the Duchesne River Basin located in northeastern Utah, is made up of portions of Wasatch, Duchesne, and Uintah Counties. Total irrigated acreage amounts to about 140,000 acres, of which about 62,000 acres is Indian land. According to estimates of the Bureau of Reclamation, (20) the average dissolved solids concentration in the Duchesne River near Randlett, Utah, will rise from a present-modified value of 0.98 T/AF (720 mg/l) to 1.59 T/AF (1170 mg/l) following construction of the Bonneville and Upalco Units of the Central Utah Project. Municipal and industrial water supplies are obtained mainly from groundwater. Thus, the impact of mineralized Colorado River water upon these users will be practically nil.

The second area in the Upper Colorado Basin, the Upper San Juan subbasin, comprises all or portions of 22 counties in southern Colorado, northern New Mexico, and southeastern Utah. Like the first area, population is sparce and agriculture dominates the economy. Unlike the Duchesne area, the gas and petroleum industry has replaced agriculture in importance in some areas. In the San Juan River near Bluff, Utah, progressive small increases in salinity are anticipated following construction of the Navajo, Hammond, and Florida Projects, and a larger rise under operation of the San Juan-Chama and the Navajo Indian Irrigation Projects. The maximum increase expected is 0.38 T/AF, of which the greater part, 0.35 T/AF, would result from consumptive use and leaching of salts from irrigated lands on the Navajo Reservation. The magnitude of the future water quality change will be too small to have appreciable effect on the limited amount of irrigated land downstream of the anticipated increase. The municipal penalty costs are also insignificant due to the small population and the relatively low hardness of the water.

Economic analysis of the Duchesne and San Juan areas indicated that a significant impact of salinity on water uses is not likely to be incurred by any Basin area unless it possesses the following characteristics in combination with appreciable future water quality degradation of the Colorado River: (1) contains large population centers, and/or (2) has a high level of industrial and irrigated agriculture development. After studying various areas within the Colorado River Basin and applying the above criteria, it became fairly obvious that significant physical and economic impacts were most likely to occur in the Lower Colorado River Basin and its contiguous water service areas. Three study areas, as shown in Figure 3, were therefore delineated below Lees Ferry.

It should be noted that the study area boundaries do not always

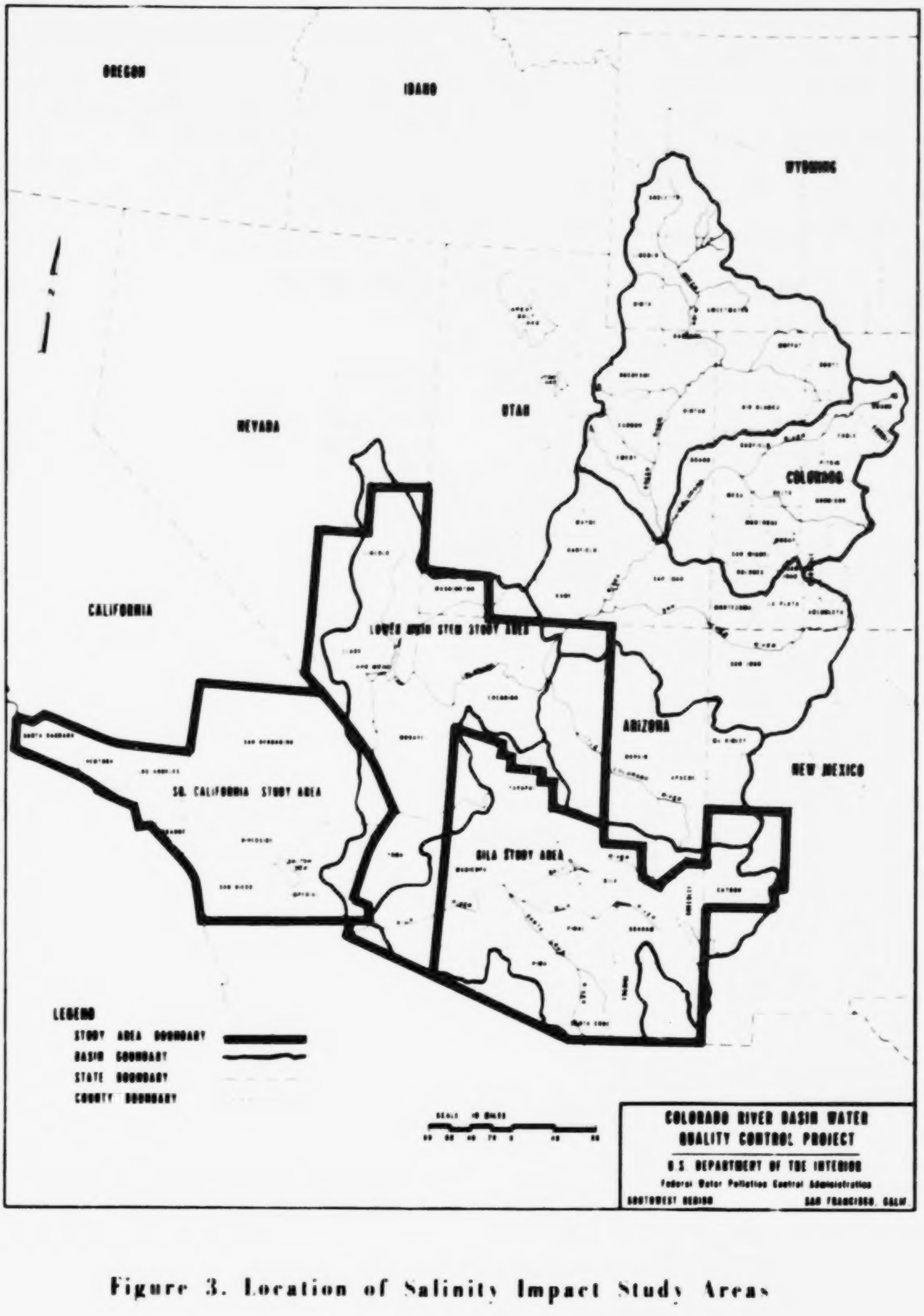
OREGON
IDAHO
WYOMING
NEVADA
UTAH
COLORADO
CALIFORNIA
LOWER BASIN STEM STUDY AREA
ARIZONA
NEW MEXICO
SO. CALIFORNIA STUDY AREA
GILA STUDY AREA
LEGEND
STUDY AREA BOUNDARY
BASIN BOUNDARY
STATE BOUNDARY
COUNTY BOUNDARY
SCALE IN MILES
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF.

Figure 3. Location of Salinity Impact Study Areas

conform to hydrologic basins. Since economic data are most often reported by civil areas rather than natural drainage areas, it was necessary to alter boundaries somewhat to achieve the objective of analyzing economic impacts. The Lower Main Stem study area includes Clark and Lincoln Counties in Nevada; Washington County in Utah; and Mohave, Coconino, and Yuma Counties in Arizona. All California land in the Lower Main Stem hydrologic subbasin is included in the Southern California study area. This study area includes the following counties: Santa Barbara, Ventura, Los Angeles, San Bernardino, Orange, Riverside, San Diego, and Imperial. The Gila study area includes Cochise, Gila, Graham, Greenlee, Maricopa, Pima, Pinal, Santa Cruz, and Yavapai Counties in Arizona, and Catrol County in New Mexico.

METHODS AND ASSUMPTIONS USED TO PROJECT MINERAL QUALITY

In order to calculate economic impacts associated with mineral quality degradation, it was necessary to establish a base quality and to project future qualities. Since long-range effects were to be assessed, including one projection to the year 2010, the decision was made to use a long-term average for base quality. Future changes in mineral quality would then be compared to the base quality in order to quantify the effect of anticipated development upon future water users. Furthermore, it was decided that the methods used to calculate future quality should be consistent with those used to determine base quality. In any such determination of mineral quality there are three factors which are critical: (1) the basic flow or hydrology of the system; (2) location and magnitude of demands for water; and (3) the location and magnitude of salt sources. These three factors must be known or estimated for each target year for which the economic impact of water quality is to be determined.

Hydrology

A long-term hydrological period of flow was selected as a base condition for several reasons, the first of which is that short-term fluctuations may be accomodated within the Basin.(24) It is well known that short-term variations in stream quality are dampened by the large mainstream reservoirs and that salts can be stored in the soils of the water-producing and water-using areas.

Secondly, it was felt that economic losses due to water quality problems of short duration might be balanced against bountiful returns obtained in years of good water quality. Long-term conditions, however, would lead to permanent changes in water-use practices and would, therefore, be reflected in detectable economic effects.

A third reason for using a long hydrologic period is that mean flows for periods longer than five years may be treated as stochastic variables, which allow the application of the principals of elementary statistics to the virgin flow or modified flow data.

Fianlly, augmentation of flow through storage regulation may be ignored for long-base periods since it evens out flow variability. A study of the 20-year yield from present and proposed storage has not been made;1/ however, it has been assumed that the 20-year mean virgin

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1/ For a study of the firm yield of the Upper Basin reservoir system, see p. 21 of reference 26. Their estimate of the firm yield from Upper Basin storage is 13.8 MAF of regulated delivery. Some additional yield could presumably be developed from Lower Basin reservoirs.

flow could not be effectively augmented by releases from storage.

The period 1942-1961, which has a mean annual virgin flow at Lees Ferry, Arizona, of 13.8 million acre-feet (MAF), was chosen as the lowest available consecutive 20 years of record in 1963 when the Project study was started. This choice is consistent with the practices of basing water quality studies on extreme low flow conditions when there is adequate assurance that the extremes are significant. There is a probability of about 0.13 that this value will not be exceeded by any 20-year mean virgin flow, and a probability of about 0.62 that the virgin flow for any one year will exceed 13.8 MAF.

Selection of a longer period of record or of any other 20-year period of record would yield a slightly higher mean annual virgin flow and mean annual salt burden. If water-use conditions were such that the increased flow could be consumptively used above Lake Powell, predicted salinity concentrations would be higher than for the 1942-1961 period of record since a larger salt burden would be carried by essentially the same stream flow below Lees Ferry. However, operational hydrology studies indicate that existing and planned holdover storage above Lake Powell would not be adequate to permit full utilization of excess supply in periods of extremely high runoff. Thus, the larger salt load produced during such periods would be carried into Lakes Powell and Mead in high

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It is also possible to augment the in-basin storage by exporting water to holdover storage in other basins as is done in the Colorado Big-Thompson Project. Thus, one might realistically expect the long-term yield to approach the long-term mean flow; however, the water will not be available as a uniform regulated annual flow. Thus, questions concerning the impact of high and low flow sequences are important.

high quality runoff resulting in lower mean salinity concentrations in the Lower Basin.

Additional hydrologic information for the Upper Basin was taken from Geological Survey Professional Papers 441 and 442 (Iorns).(27) The historic flows published in the Geological Survey Water Supply Papers were compiled for the station at Lees Ferry during the base period and were then modified to 1960 conditions of use in the Upper Basin. These modified values were used as the factors to adjust Iorns' data (1914-1957 period) to the 1942-1961 period. For the Lower Basin the historic flows recorded at U. S. Geological Survey gaging stations during the base period were modified to 1960 conditions.

Water Demand

Present water-use data were obtained by means of a limited number of field interviews and an extensive search of current literature. Municipal water-use data were obtained from the publications of agencies like the Bureau of Reclamation (BR) and the Arizona Water Company. For the most part, industrial and agricultural water-use data were obtained by means of field interviews.

Future municipal water-use projections were obtained from the current literature wherever possible (BR and Arizona Water Company). Industrial water-use projections were obtained by assuming a relationship between future water use and economic production. Consideration was also given to the industrial water-use projections made by agencies like the BR. Future water resource projects that were included in the analysis are shown in Table 12. Methods used to determine future water-use requirements for irrigated agriculture are described in another part of this chapter.

Table 12. Future Water Resources Projects[a]

Project	Completion Date	Acreage	Total Flow (acre-feet)	Total Salt Load (tons)
UPPER COLORADO RIVER BASIN				
Lyman, Wyoming	1980	0	10,000	
Silt, Colorado	1980	2,120	6,000	3,964
Emery County, Utah	1980	770	17,000	1,925
Hammond, New Mexico	1980	2,000	5,000	3,420
Seedskadee, Wyoming	2010	58,775	165,000	129,305
Central Utah, Utah				
Bonneville Unit	2010		166,000	- 31,000
Jensen Unit	1980	500	10,000	1,220
Upalco Unit	1980		20,000	
Uinta Unit	2010		20,000	
Denver, Englewood, Colorado Springs & Pueblo Diversions	2010		234,000	- 16,000
M&I Green Mountain	1980		12,000	
Independence Pass Expansion	1980		14,000	- 3,000
Homestake Project, Colorado	2010		74,000	- 10,000
Hayden Steam Plant	2010		12,000	
Bostwick Park, Colorado	1980	1,320	4,000	673
Savery-Pot Hook, Wyoming-Colorado	1980	21,920	38,000	26,304
Fruitland Mesa, Colorado	1980	16,520	28,000	8,425
Expansion Hogback	1980		10,000	
Utah Construction Company, New Mexico	1980		25,000	
Westraco-Utah Power & Light Company, Wyoming	1980		36,000	
San Juan-Chama, Colorado-New Mexico	1980		110,000	- 14,000
Navajo Indian Irrigation, New Mexico	2010	110,000	250,000	188,100
Fryingpan-Arkansas, Colorado	1980		70,000	- 15,000
M&I Ruedi Reservoir, Colorado	2010		40,000	
Four County, Colorado	2010		40,000	- 4,000
San Miguel, Colorado	2010	26,000	85,000	70,460
Cheyenne, Wyoming	2010		31,000	- 10,000
West Divide, Colorado	2010	19,000	76,000	35,530
Animas-La Plata, Colorado-New Mexico	2010	47,500	146,000	81,225
Dolores, Colorado	2010	32,000	87,000	54,720
Dallas Creek, Colorado	2010	15,000	37,000	45,000
Resources Inc., Utah	2010		102,000	

Table 12. Contd. Future Water Resources Projects[a]

Project	Completion Date	Acreage	Total Flow (acre-feet)	Total Salt Load (tons)
LOWER COLORADO RIVER BASIN				
Arizona M&I, Arizona	1980		39,000	
Marble Canyon, Arizona	2010[b]		14,000	
Dixie Project, Utah	2010	11,615	62,000	14,000
Southern Nevada Pumping	2010		253,000	
Ft. Mohave Indian Reservation	1980	18,974	76,000	19,000
Chemeheuvi Indian Reservation	1980	1,900	8,000	2,000

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[a] Marble Canyon Project deleted from Bureau of Reclamation Progress Report No. 4 (Reference No. 28).

[b] References: U. S. Department of Interior, "Quality of Water, Colorado River Basin," Progress Report No. 3, January 1967 (Reference No. 29).

A different method was used to determine present and future water use in situations where groundwater is blended with Colorado River water to make up a given entity's supply. Since water demand is frequently a function of water quality, it was necessary to consider the demand for a blend of water with different qualities. If the entity in question was utilizing Colorado River water exclusively, the intake quality was taken as the quality of the Colorado River at the point of diversion. If, however, an entity utilized Colorado River water in conjunction with a groundwater supply and blended the two, it was necessary to estimate the intake quality by determining the quality of the resulting blended supply. The projected demand for water was then modified to reflect this quality.

Salt-Load Sources

Salt-load sources in the Upper Basin were estimated primarily from data contained in the Iorns report.(27) In cases where published information was lacking, the Project used its own supplemental data which was obtained from field surveys. A description of these surveys and results obtained are presented in Appendix A.

DETERMINATION OF WATER QUALITY

A computer program which calculates water quality at critical points in the system was used to integrate the hydrologic characteristics, water demand data, and estimates of salt loads for each target year. This program, a flow and salt-routing model, was used to develop estimates of the average mineral quality levels for the years 1960, 1980, and 2010.

The computer program simulates Basin response to input data in a series of calculations for small drainage areas. Figure 4 illustrates the method used for dividing the Basin into drainage areas and establishing

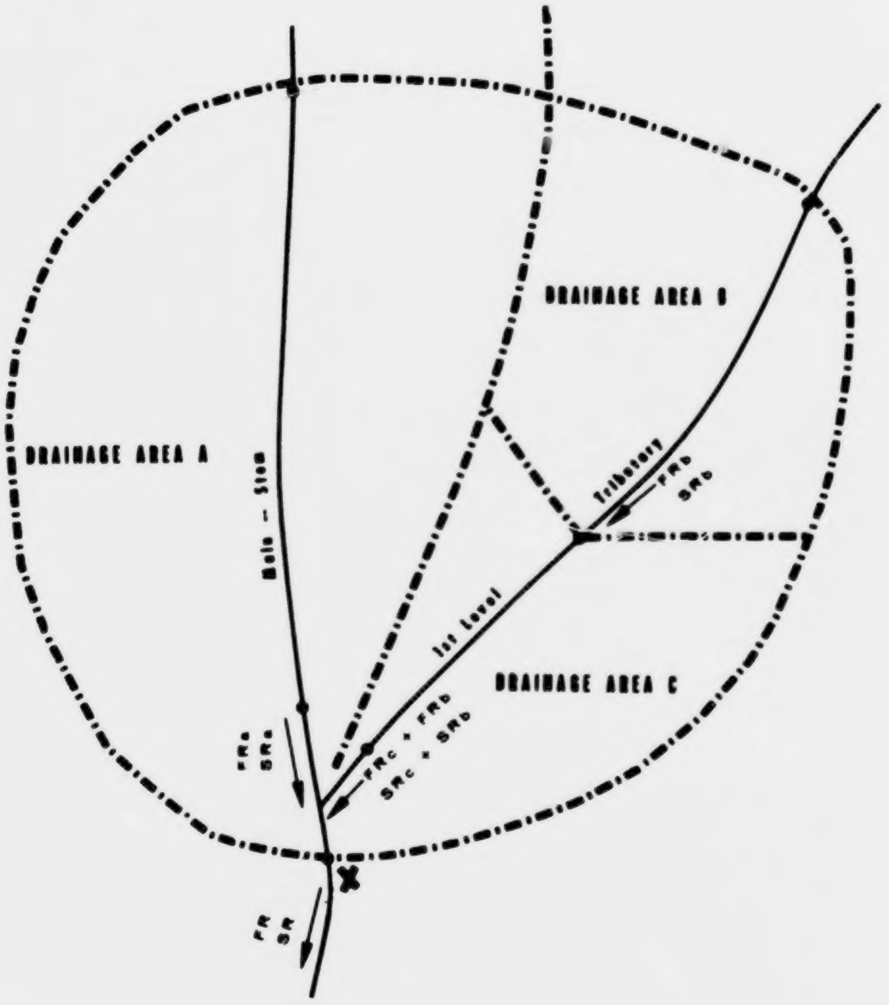

DRAINAGE AREA B
DRAINAGE AREA A
Main – Stem
Tributary
FRb
SRb
1st Level
DRAINAGE AREA C
FRa
SRa
FRc + FRb
SRc + SRb
X
FR
SR

Figure 4. Typical Drainage Area Used for Flow & Salt Routing Model for the Colorado River Basin

points at confluence of streams. Natural flow discharges and salt loads originating within the defined drainage areas were first determined. The effects of man's activities, such as depletions of water for consumptive use or addition of salt loads by irrigation, were added to the natural effects. The program then accumulates these effects and routes them downstream to be added to successive effects.

From Figure 4 the accumulated flow and salt load runoff below junction X would be $FR = FR_a + FR_b + FR_c$, and

$$SR = SR_a + SR_b + SR_c\text{, respectively.}$$

The flow discharge runoff equation for each drainage area would be

$$FR_{a,b,c} = (AN \times CN) + DS - (IA \times CI) - (P \times CP) \pm DV;$$

and the salt load runoff equation would be

$$SR_{a,b,c} = (AN \times CN) + DS + (IA \times CI) + (P \times CP) \pm DV;$$

where $FR_{a,b,c}$ = annual flow runoff in acre-feet,

$SR_{a,b,c}$ = annual salt load runoff in tons,

AN = natural drainage area in square miles,

CN = coefficient for contributions from the natural area in acre-feet/sq. mi. or T/sq. mi.,

DS = annual contribution from discrete sources in acre-feet or tons,

IA = irrigated acreage,

CI = coefficient for depletions or contributions from irrigation in acre-feet/acre or tons/acre,

P = population,

CP = coefficient for depletions or contributions by the population in acre-feet/person or tons/person, and

DV = annual diversions (imports or exports) within the drainage area in acre-feet or tons.

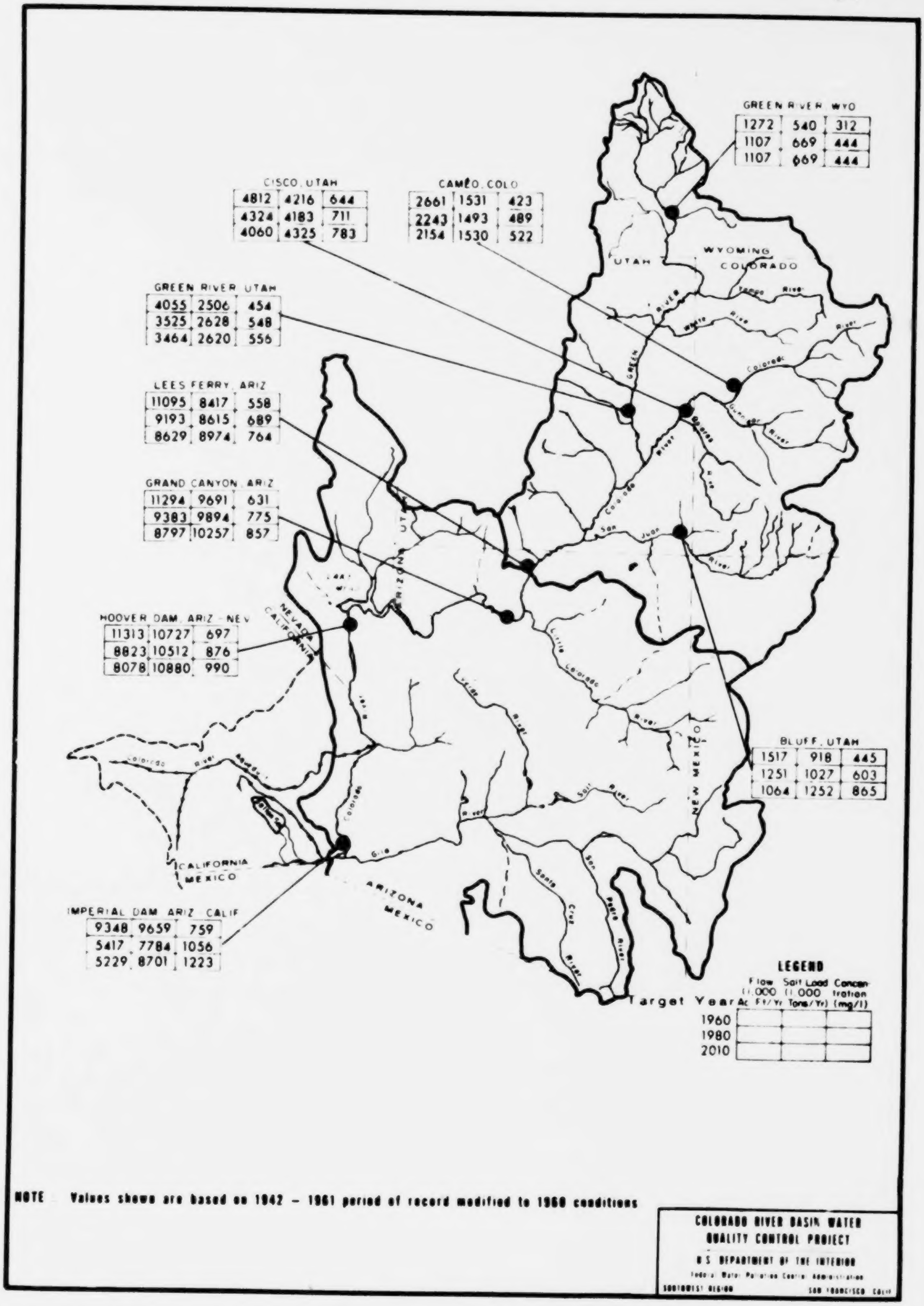
The drainage areas were divided, where possible, so that the stations or points selected for the routing model would coincide with the locations of USGS gaging stations. As the inflows of water in the Lower Basin were small compared to the Upper Basin, the routing model for the Lower Basin was simply a budget listing the various depletions of water.

TARGET YEAR MINERAL QUALITY

Flow depletions and expected salt loads from new irrigation projects, growth of existing irrigation district water demands, and increased municipal and industrial uses were projected independently and entered into the model. The model was used to correlate the data and to produce a new array of quality values for years 1980 and 2010. The water quality values obtained by this analysis are shown in Table 13 and Figure 5. Salinity concentrations were computed by the model to the nearest mg/l. This degree of refinement in reporting computer predictions was selected to allow evaluation of the small incremental changes in salinity concentrations produced by a given salt source or water resource development and to reduce rounding errors. It was not intended that a high degree of accuracy be implied as predictions of future salinity concentrations are dependent upon a number of factors which are not known with certainty.

Table 13. Water Quality Values (mg/l) for the Lower Main Stem Subbasin Obtained by Flow and Salt Routing Model for the Colorado River Basin

	1960		1980		2010	
Location	TDS	Hardness	TDS	Hardness	TDS	Hardness
Colorado River @ Hoover Dam	697	345	876	420	990	460
Colorado River @ Parker Dam	684	340	866	415	985	460
Colorado River @ Palo Verde	713	350	940	445	1082	495
Colorado River @ Imperial Dam	759	370	1056	485	1223	540


GREEN RIVER, WYO
1272 540 312
1107 669 444
1107 669 444
CISCO, UTAH
4812 4216 644
4324 4183 711
4060 4325 783
CAMEO, COLO
2661 1531 423
2243 1493 489
2154 1530 522
GREEN RIVER, UTAH
4055 2506 454
3525 2628 548
3464 2620 556
LEES FERRY, ARIZ
11095 8417 558
9193 8615 689
8629 8974 764
GRAND CANYON, ARIZ
11294 9691 631
9383 9894 775
8797 10257 857
HOOVER DAM, ARIZ - NEV
11313 10727 697
8823 10512 876
8078 10880 990
BLUFF, UTAH
1517 918 445
1251 1027 603
1064 1252 865
IMPERIAL DAM, ARIZ - CALIF
9348 9659 759
5417 7784 1056
5229 8701 1223
UTAH
WYOMING
COLORADO
Yampa River
White River
Green River
Colorado
Gunnison River
Colorado River
San Juan River
NEVADA
CALIFORNIA
ARIZONA
UT
NEW MEXICO
Lake Mead
Little Colorado River
Verde River
Salt River
Gila River
Colorado
Colorado River Aqueduct
Salton Sea
CALIFORNIA
MEXICO
ARIZONA
MEXICO
Santa Cruz River
San Pedro River
LEGEND
Target Year
Flow (1,000 Ac Ft/Yr)
Salt Load (1,000 Tons/Yr)
Concentration (mg/l)
1960
1980
2010
COLORADO RIVER BASIN WATER
QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

NOTE: Values shown are based on 1942 – 1961 period of record modified to 1960 conditions

Figure 5. Flow, Loads, & Salinity Concentrations in Streams in the Colorado River Basin

It is interesting to note that the quality at Lees Ferry is projected to increase from 558 mg/l to 764 mg/l (37 percent increase) while the quality at Imperial Dam, the last delivery point in the system, is projected to increase from 759 mg/l to 1223 mg/l (61 percent increase). These results tend to verify the conclusion that the impact of mineral quality degradation in the Colorado River Basin will be much more severe for downstream users than for upstream users.

The model describes the relative effect of the various types of salt sources on salinity concentrations. Accumulated data on flow, salt loading and salinity concentrations can be summarized by source for a number of key points in the system. Table 14 presents such a summary for the target year 1960 at Hoover Dam. As illustrated by the table, approximately 73 percent of the 1960 salinity concentration at Hoover Dam was contributed by various sources of salt loading and only 27 percent of the salinity was the result of consumptive water use including water exports from the basin.

From similar tables developed from routing model data, it is possible to determine the relative effect of projected changes on mineral quality. Future mineral quality changes at Hoover Dam due to projected consumptive use of water and added salt loads above that point are shown in Figure 6. It will be noted that nearly 83 percent of the projected mineral quality increase at Hoover Dam will be caused by increased consumptive use of water. Such a significant effect is important in view of anticipated diversions from the Upper Basin.

INDEX OF MINERAL QUALITY

For any given "steady state" of a river system, a fixed array of

Table 14. Effect of Various Factors on Salt Concentrations in Colorado River at Hoover Dam
(1942-1961 period of record adjusted to 1960 conditions)[a]

Factor	Flow (1000 AF/Yr)	Cumulative Flow (1000 AF/Yr)	Salt Load (1000 Tons/Yr)	Cumulative Salt Load (1000 Tons/Yr)	Cumulative Concentration Tons/AF	Cumulative Concentration Mg/l	Change in Concentration[b] Mg/l	Percent of Total Concentration
Natural Diffuse Sources	14,471	14,471	5,408	5,408	0.374	275	275	39
Natural Point Sources	229	14,700	1,283	6,691	0.455	334	59	8
Irrigation (Salt Contribution)	0	14,700	3,536	10,227	0.696	512	178	26
Irrigation (Consumptive Use)	- 1,883	12,817	0	10,227	0.798	587	75	11
Municipal and Industrial Sources	- 42	12,775	146	10,373	0.812	597	10	1
Exports Out of Basin	- 465	12,310	- 37	10,336	0.840	617	20	3
Evaporation and Phreatophytes	- 1,409	10,901	0	10,336	0.948	697	80	12
Storage Release from Hoover	412	11,313	391	10,727	0.948	697	0	0
TOTAL		11,313		10,727		697		100

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[a] Based on data from the following sources:
(1) Iorns, W. V., Hembree, C. H., and Oakland, G. L., "1965 Water Resources of the Upper Colorado River Basin - Technical Reports," U. S. Geological Survey Professional Papers 441 and 442.
(2) U. S. Department of Interior, "Quality of Water, Colorado River Basin," Progress Report No. 3, January 1967
(3) FWPCA unpublished records.

[b] Concentrations in this column will vary depending upon the order in which they are calculated.

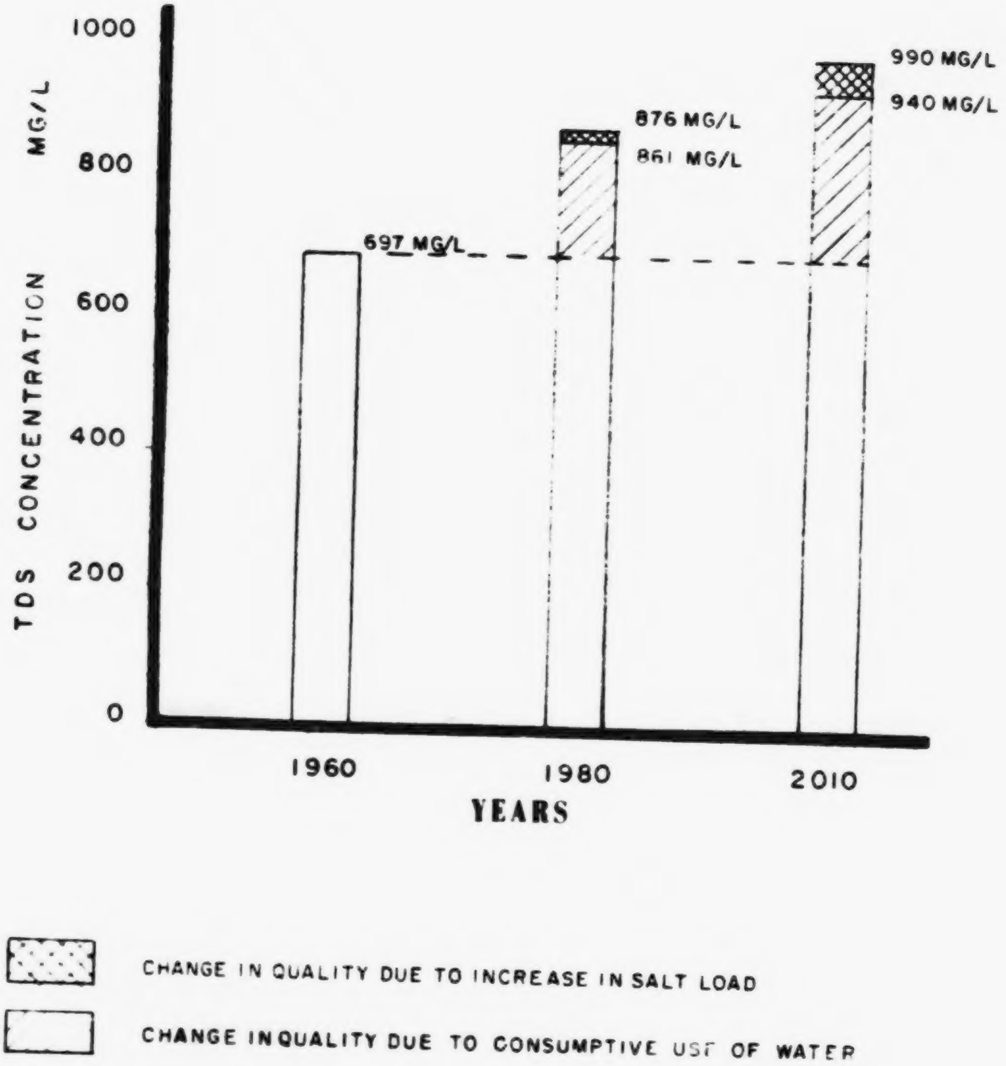


Figure 6. Future Mineral Quality Changes at Hoover Dam Due to Consumptive Use of Water & Salt Load Increases Above That Point

water quality and use data exists. A change in quality or use at any point may affect the entire system. To simplify presentation of the probable impact caused by a modification in the system, it is useful to have a single index representative of water quality for the entire system. Selection of such an index is discussed below.

Since the concentration and the volume of water withdrawn at each water-use location are important in determining total effects, one possible index representing the state of the system could be:

$$I = \sum_{i=1}^{n} D_i C_i \Big/ \sum_{i=1}^{n} D_i$$

Where: I is the mineral quality index,
D is the volume of diversion at a location,
C is the TDS concentration at a location,
i is a location index ranging from 1 to n, and
n is the total number of diversions in the basin.

A second, more simplified approach is to select a single key point in the system to which water quality at major points of use is related and utilize water quality at this key point as an index of the system. Essentially all of the economic impact of projected salinity increases will accrue to Lower Basin water users. Since Hoover Dam regulates water releases to Lower Basin users, salinity concentration at various downstream points of use can be directly related to salinity concentration at Hoover Dam. Therefore, mineral quality at Hoover Dam was selected as a simplified index of water quality for the entire Colorado Basin. For the remainder of this report, presentations of the economic impact of various proposed changes in water use are directly related to this mineral quality index at Hoover Dam.

CHAPTER IV. DIRECT PENALTY COST EVALUATION

DEFINITION OF PENALTY COST

In order to define the term "penalty cost," it is necessary to understand the term "detriments." Detriments are user costs incurred when a specific quality of water is used. A penalty cost is defined as the difference between the detriments associated with the use of two different levels of water quality; thus, it is based on similar economic conditions which permits the cost effect of water quality to be isolated. The following hypothetical situation will serve to illustrate the meaning of the terms defined above.

Assume that a city utilizing Colorado River water as its source of municipal supply has an intake hardness of 200 mg/l in 1960 and a forecasted intake hardness of 300 mg/l in 1980. The detriments in 1980 associated with using water of 200 mg/l and 300 mg/l hardness are shown as points "a" and "c" respectively in Figure 7. The difference between the detriments is the penalty cost "A" which would be incurred by the municipal users in 1980 if the hardness of their supply increasd from 200 mg/l to 300 mg/l. It should be noted that, if the intake quality remained at 200 mg/l from 1960 to 1980, there would be an increase in the detriments from 1960 to 1980 as indicated by points "a" and "d." The increase is caused by changes in economic conditions, such as a larger population affected, not by a change in the water quality. Although such a difference in detriments represents an economic penalty associated with water quality, it is not a penalty cost as defined above.

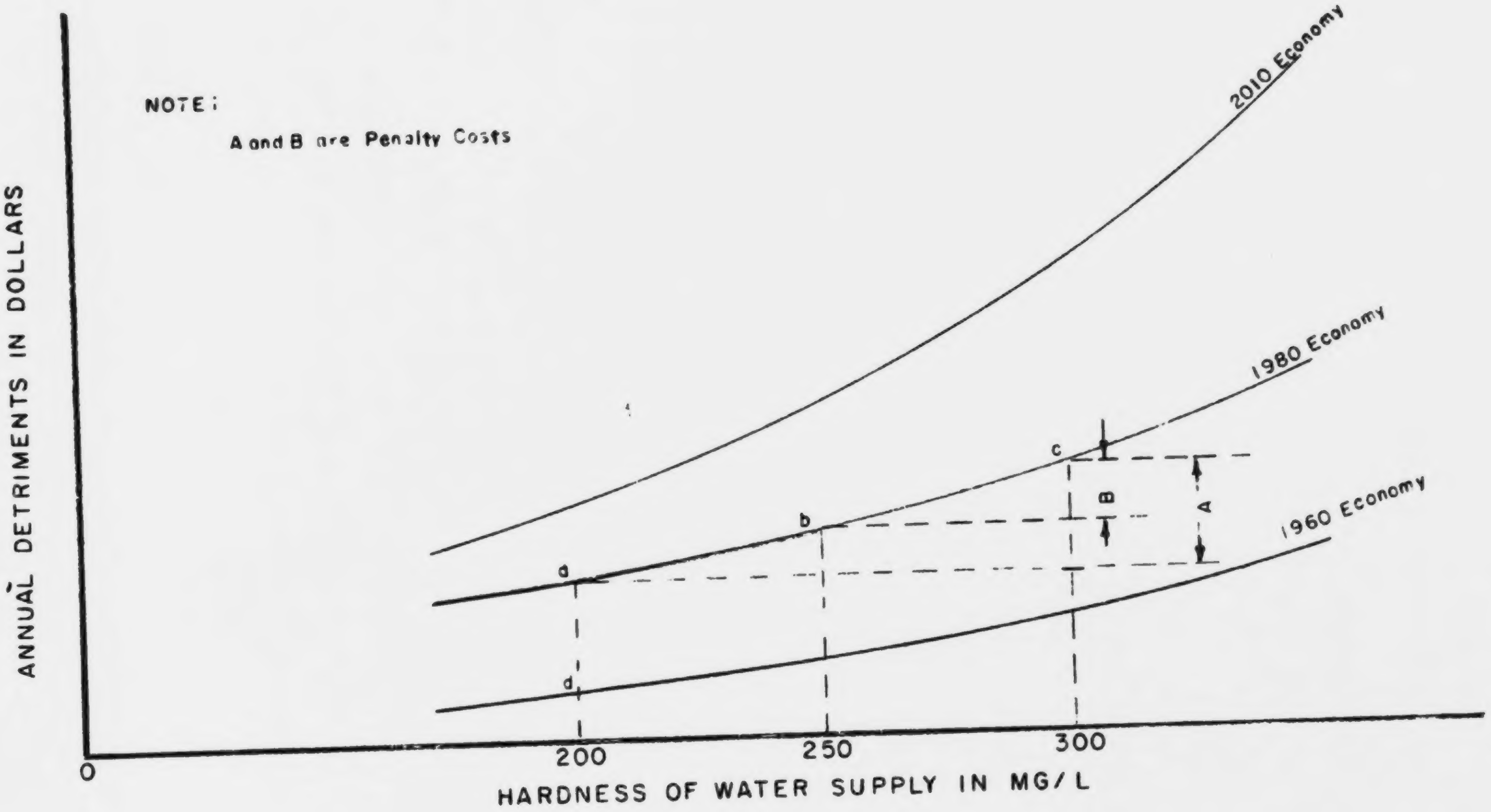


Figure 7. Illustration of Detriments & Penalty Costs Due to Water Quality Degradation

METHODS OF PENALTY COST EVALUATION

Users in the Lower Basin have recently begun to recognize that degradation of the mineral quality of Colorado River water is having a direct adverse affect upon their economic welfare. Although individual users have not felt the impact to a significant degree, there is a general awareness of the problem. In such a situation each individual affected begins searching for potential solutions which will offset the direct loss to his welfare. From various alternative solutions, the individual will generally select one which is the least costly.

In a similar fashion the Project attempted to formulate several alternatives for each major type of water use in the Basin, each of which was considered satisfactory from a practical viewpoint. Various alternatives were evaluated and one was selected for the purpose of analyzing basinwide effects. It should be emphasized that, even though one alternative was selected for use in the analysis, the Project does not propose that such an alternative be implemented in practice. This analysis was carried out for the purpose of measuring the value of anticipated changes in a physical system. The various alternatives considered and the one selected for use by the Project in its penalty-cost evaluations are discussed in considerable detail in the following sections.

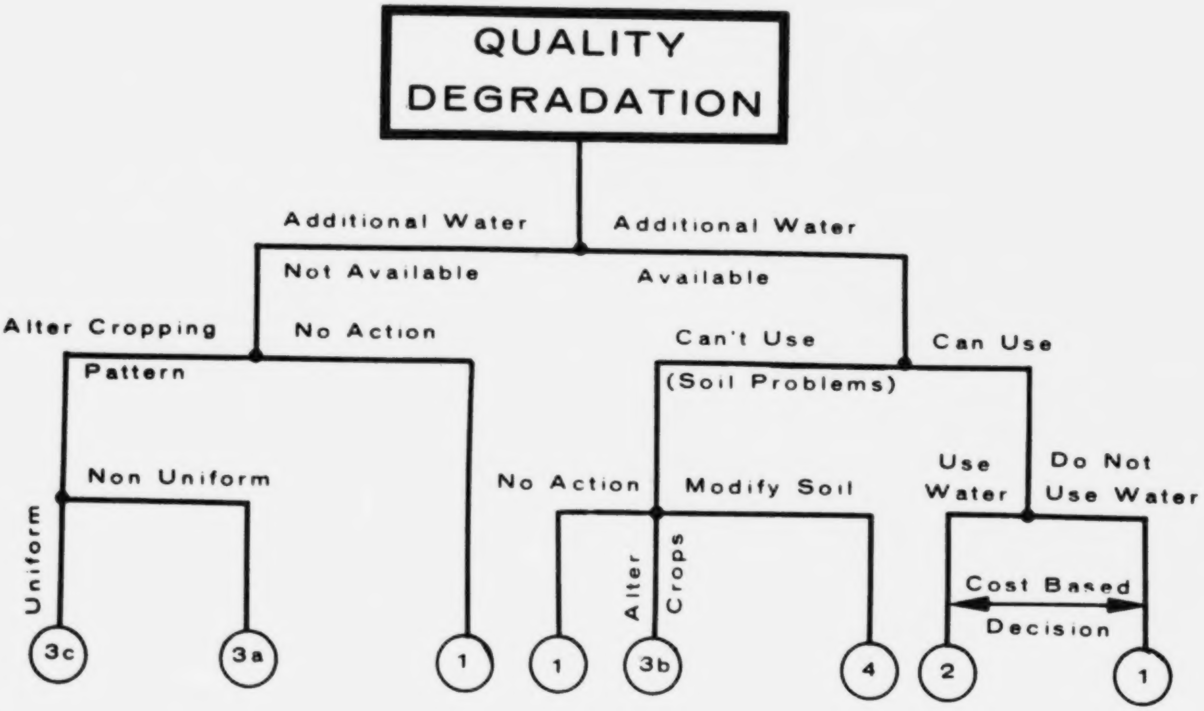
Irrigated Agriculture

Several alternatives are available to an irrigator when the quality of his water supply becomes degraded. If additional water is available and no soil problems exist, he can increase the quantity of applied leaching water. When soil conditions are such that additional leaching water cannot be applied, the alternatives are to adjust the soil conditions or replace salt-sensitive crops with less sensitive ones that require less leaching water. The remaining alternative with additional water available is to take no action and, thereby, suffer a decrease in crop yields. If additional water is not available, two alternatives exist. The acreage in production can be reduced, either uniformly or non-uniformly, or no action can be taken. All these alternatives are shown schematically in Figure 8.

The following methods were investigated: (1) the yield-decrement method, (2) the Scofield-Hill equivalent service concept,(30) (3) the "constant quality of percolate" leaching requirement formula,(9) (4) the uniform acreage reduction alternative, and (5) the selective acreage reduction alternative. The techniques for calculating penalty costs by each of these methods are discussed in the following sections.

Yield Decrement. One alternative available to an irrigator when the quality of his water supply becomes degraded is to take no remedial action. This is shown as alternative No. 1 in Figure 8. Salinity detriments in this case are considered to be the loss in yield per acre due to increased salinity in the irrigation water supply. The percent of optimum yields realized are calculated for base and for adjusted water qualities. The economic value of the difference in yield associated with the two water qualities represents the penalty costs due to increased salinity in the irrigation water.

The Department of Agriculture Salinity Laboratory at Riverside, California, has developed data(31) that show the relationship between the expected yield of various crops as a function of the root zone soil


QUALITY DEGRADATION
Additional Water Not Available
Additional Water Available
Alter Cropping Pattern
No Action
Can't Use (Soil Problems)
Can Use
Non Uniform
Uniform
No Action
Modify Soil
Alter Crops
Use Water
Do Not Use Water
Cost Based Decision
3c
3a
1
1
3b
4
2
1

ALTERNATIVE DIAGRAM

1. NO ACTION. LEADS TO YIELD REDUCTION.
2. INCREASE PURCHASE AND USE OF WATER.
3. MAINTAIN SAME TOTAL USE ON FEWER ACRES. LEADS TO MORE USE/ACRE.
    - a. Remove Least Profitable Crops ($/A-ft.)
    - b. Remove Least Tolerant Crops (Yield in $/ppm)
    - c. Remove Crops in Proportion to Acreage
4. INCREASED PURCHASE OF SOIL CONDITIONERS.

Figure 8. Irrigation Water User Alternatives for Offsetting the Effects of Mineral Quality Degradation

saturation extract[1] quality. These data were used to construct salinity-yield curves for various crops as shown in Figure 9. The percent of optimum yield with respect to salinity can be computed by determining the mean conductivity of the root zone soil saturation extract and by reading the corresponding "percent of optimum yield" from the salinity crop yield curves. Since the consumptive use, amount of applied water, and quality of the irrigation water are known, the quality and quantity of the drainage water may be calculated using Department of Agriculture Handbook 60 formulas.[2] The mean conductivity of the root zone soil saturation extract is the average of the conductivities of the applied water and the drainage water. This average value is divided by two in order to correct the conductivity of the soil solution to an equivalent conductivity of the saturation extract, as recommended by the salinity laboratory.

As previously stated, the conductivity of the saturation extract, when applied to the empirical salinity-yield relationship, gives a percent of possible yield. In order to obtain the salinity detriments for each target year, including 1960, it was necessary to choose a base quality below the 1960 target-year quality. A base quality was selected for each area and was used in all calculations pertaining to that area.

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[1] The electrical conductivity of the saturation extract of a soil was adopted by the salinity laboratory as a scale for estimating the salinity of a soil. The procedure for determining the saturation extract value involves preparing a saturated soil paste by stirring, during the addition of distilled water, until a characteristic end-point is reached. A suction filter is then used to obtain a sufficient amount of the extract for making the conductivity measurement.

[2] U. S. Department of Agriculture, U. S. Salinity Laboratory, "Saline and Alkali Soils," Agriculture Handbook No. 60, 1954, pp. 31-38. (Reference No. 10).

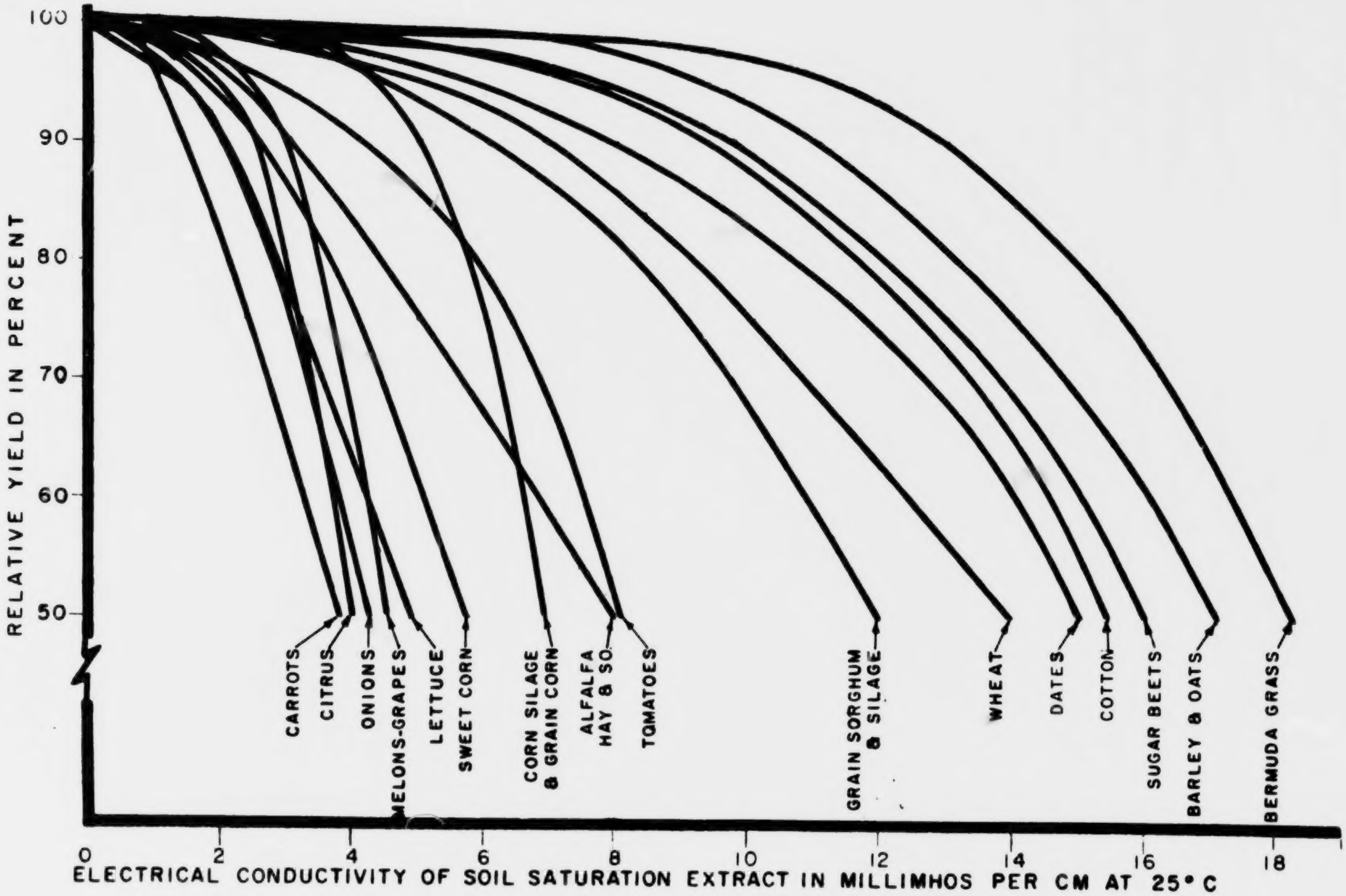

Figure 9. Salt Tolerance of Major Crops Grown in Study Areas

The salinity detriment for each crop is equal to the decrease in yield per acre times the total gross value of the crop, and is calculated according to the following equation:

$$DET_{YD} = \left(1 - \frac{PYIELD_2}{PYIELD_1}\right)(A)(V) \; ;$$

where:

DET_{YD} = Yield decrement detriment for a crop in a given area for a given quality (TDS),

$PYIELD_1$ = Percent of optimum yield at base quality,

$PYIELD_2$ = Percent of optimum yield at adjusted quality (target year),

A = Gross acreage of the crop, and

V = Gross value of crop per acre.

Gross value is used here because the technique assumes no change in farm management practices. Therefore, pre-harvest costs are still incurred, and no profit is realized for that portion of the crop lost because of quality degradation. To obtain the total detriments for each area for a given target year, the detriments for all the crops are summed. The penalty costs for 1980 and 2010 are the differences between the detriments for these two years, respectively, and the 1960 detriments. It should be noted that the actual values of the detriments have little meaning because a base quality was used to obtain them. However, the penalty costs do have meaning if the same base quality is used for all target year calculations.

Equivalent Service. As an alternative to the no-action condition, the irrigator could choose to maintain existing yields as the quality of his water supply degrades. This is shown as alternative No. 2 in Figure 8. He could accomplish this by applying more water in order to increase the leaching fraction. In this case the major problem lies in determining how much additional water would be required. Hill and Scofield considered this problem and set forth the concept of "equivalent service"(30) as one method of calculating the amount of water required. Equivalent service requires reduction in the concentration of the drainage water in order to offset the increase in concentration of dissolved solids in the applied water. This concept calls for a substantial increase in the leaching fraction in order to improve the drainage water quality.

The quantity of water required for a given crop being irrigated with a certain quality of water can be calculated by the following equation:

$$D_a = D_o \left(\frac{4Cr - 3Ca}{4Cr - 4Ca} \right) A;$$

where:

D_a = Quantity of applied water required for a crop at a given quality,

D_o = Consumptive use required by a crop,

Ca = Concentration of salts in applied water,

Cr = Average effective concentration of the soil solution, and

A = Gross acreage of crop.

As was the case with the yield decrement method, it is felt that the mean effective concentration of the soil extract is closer to one-fourth of the sum of the concentrations of the applied water and the percolate. It should be noted that this judgment leads to a more conservative estimate of penalty costs than that resulting from using the average of the concentration of the applied water and the percolate.

Maintaining the root zone water quality at its present level would be sufficient to maintain existing crop yields. However, in order to evaluate penalty costs attributable to this alternative, the volume of additional water needed to maintain present root zone quality has to be determined for the range of irrigation water quality expected in the future. It should be noted that maintenance of present root zone concentrations requires use of water in excess of the amount required to maintain salt balance.

The dollar value of salinity detriments in a given area is calculated by the following equation:

$$\text{TOTAL DET}_{ES} = \left(\frac{\Sigma D_{a2} - \Sigma D_{a1}}{E}\right)(RV_w);$$

where: TOTAL DET_{ES} = Total equivalent service detriments for a given area at adjusted quality,

ΣD_{a2} = Summation of applied water required for all crops at adjusted quality (target year),

ΣD_{a1} = Summation of applied water required for all crops at base quality,

RV_w = Residual value of water, and

E = Overall delivery efficiency.

The penalty costs for 1980 and 2010 are the difference between the detriments for these two years, respectively, and the 1960 detriments.

A short discussion is in order at this point concerning the economic value of water used for irrigation. Water for irrigating agricultural crops is often in scarce supply, thus it has an economic value. Several methods may be used in determining the value of irrigation water. The most widely accepted method is the "market price," where water is not appurtenant to the land. Very few areas have a true market price for water, i.e., where water is traded or rented for the season just like any other commodity. In the absence of a market price for irrigation water in the Colorado River Basin, the "residual value" is the most widely accepted substitute. The residual value of irrigation water represents the average amount a farmer can pay for water without impinging on the going rate of return to other inputs (land, labor, capital, overhead, and management) used in crop production. Crop budgets were used to calculate crop receipts, crop expenses, and the return to water. Total residual value for each crop and residual value per acre-foot of water applied were both calculated.

When the TDS concentration of the applied water equals the present mean root zone quality for any crop, no amount of water of the same quality can dilute it enough to offset the concentrating effect caused by consumptive use and the technique of equivalent service is no longer applicable. Therefore, salinity detriments calculated in this manner become infinitely large when the quality of water nears the present mean root zone quality of the most inefficiently irrigated crop.

Since excess amounts of water are applied in some areas and the supply of water is limited in others, equivalent service has been found to be not directly applicable to areas in the Lower Colorado River region.[1]

Constant Quality of Percolate. The equivalent service concept discussed in the previous section is one method of calculating leaching water requirements. Another method is known as the "constant quality of percolate." The theories used as a basis for this method are described in detail in Handbook 60 published by the U. S. Department of Agriculture.(10) The equation developed for calculating the leaching water requirement for a given applied water quality and for a particular crop is:

$$LR = \frac{TOL}{TOL - QUAL} (U)(A) ;$$

where: LR = Total leaching requirement for a crop at a given quality,

TOL = Salt tolerance of crop in mmhos/cm,[2]

QUAL = Quality of irrigation water in mmhos/cm,

U = Consumptive use (evapotranspiration), and

A = Gross acreage of crop.

Total detriments for a given area are calculated according to the following equation:

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[1] The staff of the Economic Research Service, USDA, collaborated in the investigations; results were also reviewed with Dr. Bernstein and the staff of the salinity laboratory, as well as Dr. Vaughn Hansen and Mr. Raymond Hill who served as consultants to the Project.

[2] According to Mr. L. V. Wilcox, the conductivity of the drainage water associated with a 50 percent decrease in yield is nearly the same as the conductivity of the root zone saturation extract associated with a 10 percent reduction in yield.

$$\text{TOTAL DET}_{CQP} = \frac{(\Sigma LR_2 - \Sigma LR_1)}{E} (RV_w) ;$$

where: TOTAL DET_{CQP} = Total detriments for a given area at adjusted quality for target year,

ΣLR_2 = Summation of leaching water requirements for all crops at adjusted quality for target year,

ΣLR_1 = Summation of leaching water requirements for all crops at base quality,

RV_w = Residual value of water, and

E = Overall delivery efficiency.

The penalty costs for 1980 and 2010 are the differences between the detriments for these two years, respectively, and the 1960 detriments.

To determine the penalty costs associated with quality degradation, it is necessary to account for the increase in conveyance losses and to determine the dollar value of this quantity of water. This is done by dividing the increase in leaching water by the overall delivery efficiency.1/ The costs added by the need for extra labor, more fertilizer, and additional drainage associated with the application of more irrigation water should be added to these detriments. The latter has been shown to be quite substantial, sometimes equal to the value of the water itself.

In many locations waters of the Colorado River are fully appropriated or systems are used to capacity. In such cases an irrigator may be unable to purchase more water at a reasonable cost. He does have the option, however, of reallocating the priorities of use without

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1/ This includes conveyance, main system, and farm lateral losses.

increasing total consumption. In evaluating the costs of this option, the water requirement is determined as explained above except it is assumed that the additional water would be available from a reduction in irrigated acreage. Thus, slightly less additional water is required in this case since quality control water is not needed on the acreage taken out of production. The methods used in the acreage reduction analyses are described in the following sections.

Uniform Acreage Reduction. In the event additional water is not available for leaching as the quality degrades, an irrigator may take a portion of his crop land out of production and use the water thereby saved to increase the amount of leaching water applied to the remaining crop acreage. Even though this may prevent any yield reduction of the remaining crops, the profit that would have been made on the crops taken out of production is lost. Three methods of reducing acreage were investigated: (1) removal of a portion of all crops in proportion to total acreage (uniform reduction), (2) removal of the least profitable crops, and (3) removal of the least salt-tolerant crops. These alternatives are shown as "3c," "3a," and "3b" respectively in Figure 8.

The first step in determining detriments by the uniform acreage reduction technique is to calculate the leaching water requirements associated with a base quality and an adjusted quality for the target year. The "constant quality of percolate" method is used to obtain these leaching water quantities. The next step is to calculate the total volume of water required at the adjusted quality using the following equation:

$$R_2 = \sum_{i=1}^{n} \left(\frac{CU}{EFF} + LR_2 \right) ;$$

where: R_2 = Total volume of water required at adjusted quality,

CU = Total consumptive use (evapotranspiration) of the i^{th} crop,

EFF = Field efficiency, and

LR_2 = Total leaching requirement for the i^{th} crop at adjusted water quality.

To obtain the percentage of land to be removed, let

$$P = \frac{\Delta LR}{R_2} \quad (100\%) ;$$

P = Percent of land to be removed from production, and

ΔLR = Additional leaching requirement, $(\Sigma LR_2 - \Sigma LR_1)$, associated with quality degradation.

Careful analysis reveals that the percentage, "P" determined by the above equation is slightly over-estimated since no additional leaching water is needed on the land removed from production. To obtain the actual percent of land to be removed, it is necessary to use a successive approximation technique.

First, the true quantity of additional leaching water, LR', needed on the acreage that remains is calculated by the following equation:

$$\Delta LR' = PR_2 - P^2R_2 + P^3R_2 - P^4R_2 + \ldots . + P^nR_2 .$$

The actual or true percent to be removed, P', is then equal to $\frac{\Delta LR'}{R_2}$. By substitution, the following equation can be derived:

$$P'R_2 = PR_2 - P^2R_2 + P^3R_2 - P^4R_2 + \ldots. + P^nR_2 ,$$

and

$$P' = P - P^2 + P^3 - P^4 + \ldots. + P^n .$$

If P is less than 100%, which it will be, the sum of the infinite series can be expressed as $P' = \frac{P}{1 + P}$. After P' is determined, the total salinity detriments can be calculated by the following equation:

$$\text{TOTAL DET}_{UAR} = \sum_{i=1}^{n} (A_iV_iP') ;$$

where: TOTAL DET_{UAR} = Total uniform acreage reduction detriments for a given area at adjusted quality,

A_i = Gross acreage of i^{th} crop before reduction, and

V_i = Net value of i^{th} crop.

The net value is used because production costs are not incurred and only profit is lost.

Selective Acreage Reduction. Another acreage reduction method involves taking out of production the least profitable crops. The first step in this method is to calculate the leaching water requirements associated with a base quality and the adjusted quality for the target year by the "constant quality of percolate" method. The additional leaching requirement, ΔLR, due to quality degradation is the difference in the leaching water requirements referred to in the previous section. The quantity, ΔLR, is the amount of water that would be saved by reducing the acreage. The next step is to arrange the crops in order of increasing economic return from water use and then to calculate the total amount of water required by each crop according to the following equation:

$$r_2 = \left(\frac{CU}{EFF} + LR_2\right) ;$$

where: r_2 = Total water required by the i^{th} crop,

CU = Total consumptive use (evapotranspiration) of the i^{th} crop,

EFF = Field efficiency,

LR_2 = Total leaching requirement of the i^{th} crop at adjusted quality.

The next step in the analysis is to determine if the total amount of water required by the least profitable crop is less than ΔLR. If it is, the entire crop is removed from production and ΔLR is reduced by r_2 of the crop removed. The same comparison is then made between the amount of ΔLR remaining and the total amount of water required by the next lowest profitable crop. If the r_2 of this crop is less than the portion of ΔLR remaining, the entire crop is removed and the process is repeated.

At some point in the process, the portion of ΔLR remaining after several crops have been removed will be less than the total amount of water required by the next crop in line for removal. (Actually this could be the case with the least profitable crop grown, or the first considered.) When this point in the process is reached, it becomes necessary to determine the portion of this crop to be removed. The actual percentage of the crop to be removed, F, is equal to $\frac{D}{1 + D}$ (100 percent). The value of D is determined by dividing the portion of ΔLR

remaining at this stage by r_2 of the crop being considered. At this point, the analysis becomes identical to the uniform acreage reduction technique. The values D and F are similar to the values P and P', respectively.

After F is determined, the total salinity detriments can be determined by the following equation:

$$\text{TOTAL DET}_{SAR} = \sum_{i=o}^{i=x-1} (A_i V_i) + A_x V_x F \; ;$$

TOTAL DET_{SAR} = Total selective acreage reduction detriments for a given area at adjusted quality,

A_o = 0,

X = Reference number of the last crop affected (the numbering system begins with the least profitable and proceeds to the most profitable),

A_i = Gross acreage of the i^{th} crop,

V_i = Net value of the i^{th} crop,

A_x = Gross acreage of the i=x crop, and

V_x = Net value of the i=x crop.

A third acreage reduction method, which involves selective removal of those crops having the greatest yield loss per unit of root zone concentration increase, was not used by the Project.

Labor, Fertilizer, and Drainage. When more irrigation water is applied, additional labor costs are incurred; additional amounts of fertilizer are lost; and additional drainage facilities may be needed. In the case of additional labor costs it was assumed that irrigators would tend to decrease the interval between irrigations. In order to maximize the interval, an irrigator would apply the maximum amount of water which could be beneficially used during each irrigation. It follows that any substantial increased water requirement would necessitate more irrigations per year. The cost of additional irrigations was assessed at $2 per foot of required additional irrigation water in excess of three inches. The initial three inches of additional water was assessed no labor cost. The foregoing values are based on an application of six inches per irrigation at a cost of approximately $1 per irrigation.

Fertilizer losses were calculated according to a first-order chemical solution reaction equation. For convenience, this equation was expressed in the form:

$$L = L_o P^n ;$$

where: L_o = Quantity of fertilizer presently applied,

L = Quantity of fertilizer remaining,

P = Percent of fertilizer remaining under present conditions, and

n = Ratio of the volume of drainage with degraded water supply to present volume of drainage.

From this equation, the loss in nitrogen fertilizer associated with increases in drainage water may be calculated. This amount is multiplied by the 1960 fertilizer cost to establish a dollar penalty cost ($.12/lb.).

Drainage facilities were assessed no penalty costs for two reasons. First, it was found that irrigation districts build facilities as they are needed; and secondly, the additional leaching water required because of water quality degradation can easily be carried by the existing closed drain systems. Hence, the size of drains would not have to be increased due to additional volumes of percolating water.

Selection of Best Method. Penalty costs associated with each of the alternatives discussed above were calculated for each of the major irrigation water-use areas below Hoover Dam, and the results compared. Figure 10 shows such a comparison for a typical water-use area.

Within each of the study areas, water users utilize various combinations of alternatives in an attempt to minimize the economic impact of salinity increases in their water supply. Given sufficient data with regard to the acreage and crops to which each alternative is applied, it would be possible to accurately evaluate the magnitude of present salinity detriments. However, such data is not available. Also, the accuracy of projections of future detriments based on present combinations of alternatives would be questionable as changing conditions might alter the selection of alternatives in the future. It was thus desirable to select one alternative as a means of evaluating present and future penalty costs. The selective acreage reduction method, the least cost alternative, produced inconsistent results and was rejected. The yield decrement method, which assumes no increased use of water nor any acreage reduction, was selected as it was considered to be most applicable to conditions in the three study areas. This method results in a conservative estimate of penalty costs since any combination of other methods would result in higher costs. Thus, present penalty costs are probably higher than estimates presented in this report, but a more accurate evaluation cannot be made at this time.

Industrial

The study of industrial penalty costs of mineralized water supplies

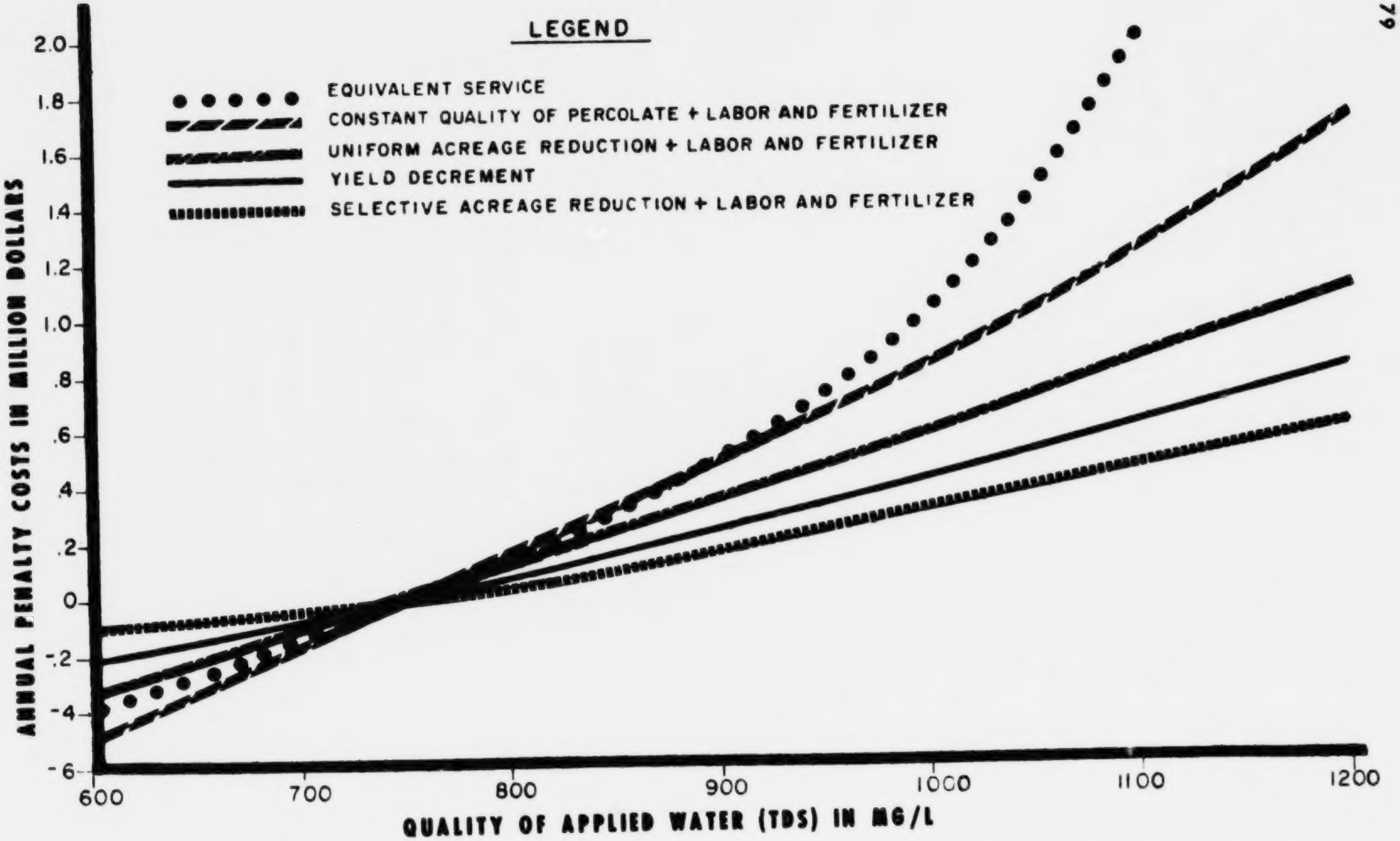

Figure 10. Comparative Results of Irrigated Agriculture Penalty Cost for a Portion of Yuma County - 1960

involves two of the four major types of industrial uses classified in Chapter II, namely cooling and boiler feed. The large number and variety of manufacturing industries in the major centers of water use, especially in Southern California,[1] made it impracticable to attempt an evaluation of effects on process waters within the scope of this study. In addition, process water use falls into two categories: (1) use that is insensitive to small incremental changes in mineral concentration, or (2) use that requires a completely demineralized supply. In either case the effect of changes in mineral quality over the range of concentrations expected to prevail is considered to be unmeasurable. General purpose water, or that used for plant drinking water, sanitation, lawn irrigation, and fire protection, is small in volume compared with other types; and for some applications, such as general cleaning and fire protection, the mineral content is not very important.

In view of these considerations, the industrial penalty costs derived in the Project's study are somewhat understated. There is no doubt, however, that the included costs cover a major portion of the fresh water used in manufacturing. In the United States as a whole over 74 percent of all industrial fresh water is used in cooling and boiler feed,(33) and in the state of California 67 percent is so employed.(34) A survey of water use in the chemical and metallurgical complex at Henderson, Nevada, made in August, 1964, by the Nevada Department of Public Health(35) showed 80 percent of the water to be employed for cooling, four percent for boiler feed, and the remaining 16 percent for processing, sanitary, and miscellaneous purposes.

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[1] Bureau of the Census, "Statistical Abstract of the United States," 1964, lists 17,665 manufacturing plants in the Los Angeles-San Diego metropolitan areas. (Reference No. 32).

There are two pertinent types of cooling and boiler systems: those which are not sensitive to mineral quality and those which are sensitive to mineral quality. High-pressure boilers require a demineralized supply; thus, they are not sensitive to minor changes in plant intake water quality. Similarly, specially designed cooling towers can accept brackish or highly saline waters; thus, they are insensitive to water quality.

Low-pressure boilers and cooling towers on fresh water systems, however, can tolerate only a limited concentration of dissolved mineral constituents. These systems, therefore, are directly affected by changes in mineral quality. This analysis is based entirely on an evaluation of penalty costs associated with Colorado River water used in sensitive systems. Therefore, all references to cooling and boiler feed water are meant to imply such use in sensitive systems only.

Current practice in the region has established the tolerance limit for low-pressure boilers to be in the range of 2,000 to 3,500 mg/l of TDS. There are several suggested requirements for mineral quality limits of boiler feed supply water which depend on the operating pressure of the boiler system.(6, 36) (See Table 1 in Chapter II.) Limited investigations of manufacturing plant practice made in the Colorado River Basin indicated that steam for plant processes is generated at comparatively low pressure, 300 psi and under. This is in contrast with operation of modern thermoelectric power stations where very high pressures are often employed. Accordingly, the value of 3,500 mg/l was used in the Project's study as a basis for the determination of penalty effects of saline boiler feed water.

For the Colorado River Basin, it appears that upper limits of dissolved solids for cooling water supplies are somewhat lower than for boiler feed water supplies. The limited studies which the Project was able to make indicate that the maximum in actual practice ranges from 1,000 mg/l to 2,500 mg/l. Accordingly, a value of 2,000 mg/l seems typical and was used as a basis for penalty cost assessment.

To simplify the calculation of industrial penalty costs, a single tolerance value was established for a system which considered both boiler feed and cooling use. It was found that cooling water use accounted for at least seven times the boiler feed usage (Table 15); and, based on this information, a volume-weighted tolerance was calculated to be approximately 2,200 mg/l.

Material balance in these systems establishes the quantity of discharge water required for any level of water use, intake quality, and system tolerance. Increasing concentrations of dissolved mineral constituents in the feed water necessitates an increase in the discharge requirement, and thus an increase in the water intake requirement, in order to prevent salt accumulation within the system. The increase in water use, the 1960 cost of water, and feed-water treatment costs were used in the assessment of industrial penalty costs.

The cleaning and sanitary water use portions of the industrial supply were assessed no user penalty costs. Only those costs incurred in providing and treating additional makeup water for cooling and low-pressure boiler systems were used in assessing industrial penalty costs.

Four major steps were required to evaluate industrial penalty

Table 15. Annual Manufacturing Water Requirement by Type of Use in California 1957-59

SIC Code	Type of Industry	Total Intake Acre-Feet	Cooling Acre-Feet	Cooling % of Total	Processing Acre-Feet	Processing % of Total	Boiler Feed Acre-Feet	Boiler Feed % of Total	Sanitary & Misc. Acre-Feet	Sanitary & Misc. % of Total
290	Petroleum Refining	148,000	128,500	86.9	3,850	2.6	13,490	9.1	2,070	1.4
200	Food	93,600	44,800	47.8	30,900	33.0	4,680	5.0	13,500	14.4
280	Chemical & Allied Products	60,600	31,300	51.6	21,000	34.7	5,340	8.8	3,090	5.1
260	Paper & Allied Products	24,200	6,500	26.8	16,250	67.0	655	2.7	849	3.5
320	Stone, Clay & Glass	27,900	11,000	39.3	14,700	52.6	559	2.0	1,680	6.0
340	Fabricated Metal Products	5,070	665	13.1	3,070	60.6	137	2.7	1,190	23.5
370	Transportation Equipment	12,600	1,110	8.8	5,460	43.4	302	2.4	5,710	45.4
330	Primary Metals	9,890	4,400	44.3	1,580	16.0	1,220	12.3	2,620	26.5
240	Lumber (wood except furniture)	27,100	10,850	40.1	4,070	15.0	10,050	37.1	2,080	7.7
	Sub-Totals	408,960	239,125		100,880		36,433		32,789	
	Percent of Total	-- 100.0	--	58.5	--	24.6	--	8.9	--	8.0
	Total for all Manufactures	421,700	242,500		104,100		37,100		37,900	
	Percent of Total	100.0	--	57.5	--	24.7	--	8.8	--	9.0

costs: (1) present and future intake water demands for the cooling and boiler feed water categories of use were estimated; (2) the quality of available supplies, including the effect of blending different supplies, was determined; (3) the required increase in water intake to offset quality degradation was calculated; and (4) the penalty costs associated with quality degradation were derived. Methodology used in the penalty cost assessment varied slightly between the study areas, but the basic four-step approach was used in all. A discussion of each step, with an explanation of the differences in methodology used for specific areas, is presented in the following sections.

Intake Water Requirements. Intake water requirements were estimated by the input-output model (see Chapter V) method in the Lower Main Stem study area and by trend-extrapolation methods in the Southern California study area. As explained in the section entitled, "Determination of Direct Penalty Costs, Gila Study Area," it was determined that industrial user penalty costs could not be calculated for the Gila study area.

Cooling and boiler feed intake water requirements for each economic sector of an input-output table can be calculated by the following equation:

$$U = (TGO)(W_i)(\%) / 325851 ;$$

where: U = Cooling and boiler feed use in acre-feet,
TGO = Total gross output in \$,
W_i = Water use coefficient in gal/\$, and
$\%$ = Percent of total use for cooling and boiler feed purposes.

As previously noted, this relationship was used for industries located in the Lower Main Stem study area because an extensive study of the subbasin economy had been completed and the input-output, or transactions, table had been assembled.

At the time of this phase of the Project's study, the input-output table had not been constructed for the Southern California area; therefore, more conventional techniques of trend-extrapolation were used for Southern California. Such techniques are well known and will not be discussed here. The data and assumptions which were utilized are discussed in the last section of this chapter.

Quality of Supply. As described in Chapter III, the mineral quality of the Colorado River was determined by a computer program at critical points throughout the Basin for each of the target years. No additional calculations were required for those industries served directly from the river.

Some industries were known to rely on a blended water supply from the Colorado River and one or more other sources. The determination of the blended quality in such situations is straightforward once the volume and quality of each source have been established. For a three-source blended supply,

$$q_b = \frac{(q_1)(F_1) + (q_2)(F_2) + (q_3)(F_3)}{F_1 + F_2 + F_3}$$

where: q_b = quality of the blended supply,

q_1, q_2, q_3 = mineral qualities of each source

F_1, F_2, F_3 = volumes of water from each source used in the blended supply.

Many assumptions must be made to determine the quality of a blended supply. A discussion of assumptions made and the resulting qualities appear in the last section of this chapter entitled, "Determination of Direct Penalty Costs."

Incremental Water Requirement. A mathematical relationship, derived from salt-balance and water-balance equations for a closed system, was used to determine the amount of additional water required to offset any increase in dissolved solids projected for each supply. The relationship is:

$$\Delta I = U\left[\frac{T\,(Q_2 - Q_1)}{(T - Q_2)\,(T - Q_1)}\right]$$

where: ΔI = Change in intake volume in acre-feet resulting from the change in quality from Q_1 to Q_2,

U = Cooling and boiler feed water use in acre-feet,

T = Tolerance of system in mg/l or tons/acre-foot, and

Q_2, Q_1 = Quality of intake in mg/l or tons/acre-foot.

Penalty Cost Assessment. The difference in makeup water requirements at any two levels of quality, multiplied by the unit cost of water, equals the first detriment associated with a change in water quality. Since the additional makeup water needs to be chemically treated in the same manner as the rest, a second detriment is computed by multiplying the incremental amount of makeup water by its unit cost of treatment. Costs of treating cooling water vary according to the type of treatment, scale of the operation, and local costs of chemicals.

Municipal

Although irrigation is the major water use in the Basin, municipal use is also significant. Hardness, which is closely correlated with dissolved solids content, creates undesirable effects in domestic uses. Three alternative methods of evaluating the economic impact upon municipal uses were examined: (1) the acceptance of undesirable effects, (2) home water softening, and (3) central softening. Each of these methods is discussed in the following section.

Acceptance of Undesirable Effects. Domestic users may elect to accept the consequences of a degraded water supply, in which case the economic penalties associated with soap use, corrosion, and evaporative cooling systems are incurred. However, only the additional soap costs were used in evaluating penalty costs. Howson(37) studied the relationship between hardness and soap use, and his results indicate an approximate linear relationship between hardness and annual soap cost per person. The equation applicable for the Lower Colorado River region is:

$$C = K_1 + K_2 H ;$$

where: C = Annual per capita cost of all cleaning products,

H = Total hardness of the water supply in mg/l,

K_1 = \$8.224 when $H \geq 300$ mg/l and \$9.60 when $H < 300$ mg/l, and

K_2 = \$0.0128/mg/l when $H \geq 300$ mg/l and \$0.0084/mg/l when $H < 300$ mg/l.

In this case, K_1 represents the annual per capita expenditure for cleaning agents, whereas K_2H represents the annual per capita cost of cleaning agents lost through chemical association with water hardness. As hardness increases, this non-beneficial soap loss also increases. The detriments then are calculated as follows:

TOTAL DET = (C) (population affected);

where: TOTAL DET = Total detriments considered when undesirable effects of a degraded supply are accepted, and

C = Annual per capita cost associated with specific hardness.

The penalty cost is the difference between the two target years' "total detriments."

Penalty Cost = (C) (population affected)

Other forms of economic loss incident to a hard domestic water have been recognized, of which the following four seem most important:

(1) Accelerated depreciation and higher maintenance costs of hot-water appliances, pipe, and fittings due to scaling and corrosion;

(2) Higher fuel costs caused by heat losses in water heaters (these losses are a consequence of hard scale formation on heating coils, tubes, and similar fittings);

(3) More rapid wear of fabrics (clothing, linens) washed in hard water, owing to longer time needed for washing;

(4) Cost of bottled water for drinking and culinary uses (an unpalatable mineralized water supply may induce consumers to buy relatively expensive bottled water).

The sum of losses (1) and (2) has been reported from several different sources to range from \$22 to \$70 annually for a family of four persons. Available estimates of savings by use of soft water to offset excess fabric wear range from \$8 to \$75 annually per family. Although these losses are known to exist, several studies - including one conducted by a member of the Project staff in 1964 - have failed to find acceptable relationships between quality and incurred cost for these four effects. The Project staff concluded that it would be incorrect to assume any direct linear relationship between quality and user cost. Therefore, no attempt was made to evaluate losses associated with these four factors although it is recognized that such losses may outweigh those associated with soap and detergent wastage.

For this alternative it was assumed that part of the community would elect to purchase home softeners and the remainder would elect to incur increased costs for soaps and detergents to offset the increased hardness. The penalty costs associated with the use of home softeners is derived by:

$$\text{Penalty Costs (Home Softeners)} = P_1b_1 - P_2b_2 ;$$

where: P_1 = Number of people using home softeners with Colorado River water at the projected quality level,

b_1 = The unit cost of home softening at the corresponding water quality level, and

P_2, b_2 = similarly defined, except Colorado River water is taken at the 1960 quality level.

Estimates for total future population were provided the Project's economic contractor.(38) Field interviews with officials of individual water softening companies were made in order to determine the percentage of the present population using home softeners. The percentages of softener users for future water quality conditions were estimated from the information contained in Howson's article.(37) From these sources of information, a conservative range of increases (5 to 15 percent) in the percentage of people using softeners was assumed for future quality conditions.

The variables, b_1 and b_2, in the equation for home softener penalty costs represent the unit costs of home softening in dollars per capita per year. The values used for the "b" terms were derived empirically from rate schedules obtained in interviews with representatives of individual water softening companies. Although not all people employing home softening units do so on a rental basis, the unit cost of rented units compares favorably with the unit cost of purchased units if the purchase price is amortized over a ten-year period. For this reason the unit cost on a rental basis, which is easier to work with both conceptually and mathematically, was utilized in the determination of home softener detriments. An average family of three to five persons(39) and an average daily usage of softened water of 50 gallons per capita were used to determine the grain capacity of the softening unit required and "b" values referred to earlier.

Penalty costs for this alternative are also incurred by the portion of the community not using home softeners as reflected in increased cost of soaps and detergents. It should be noted that this is a consequence affecting only those persons who do not seek a remedy in water softening. The penalty costs for the second effect of this alternative are calculated by the following equation:

Penalty Costs (Non-Use of Home Softeners) $= C_1P_1 - C_2P_2$;

C_1 = Annual per capita costs associated with future hardness levels,

C_2 = Annual per capita costs associated with 1960 level of hardness, and

P_1, P_2 = Number of people not using home softeners at projected quality level and 1960 quality level, respectively.

The total penalty costs for this alternative are the sum of the penalty costs for the two effects.

Central Softening. Municipal users could elect to install central softening facilities as the third alternative. The detriments for this alternative are calculated as follows:

Detriments (Central Softening) $= Q \times \Delta H_1 \times d + (K_1 + K_2H_1)$;

Q = Annual volume of water treated,

ΔH_1 = The difference in hardness between the plant influent and effluent,

d = Unit operating cost of central softening expressed in dollars per 1,000 gallons per 100 mg/l hardness removed,

K_1, K_2 = Constants defined under first alternative, and

H_1 = Hardness of the plant effluent.

Since a plant is usually designed for a particular quality effluent, the quality of the effluent remains constant. Thus, $H_2 = H_1$ so that the term $(K_1 + K_2H_1)$ cancels out. Penalty costs are therefore calculated as follows:

$$\text{Penalty Costs (Central Softening)} = Qd(\Delta H_2 - \Delta H_1) ;$$

ΔH_2 = Difference in hardness between a future target year quality and the plant effluent quality,

ΔH_1 = Difference in hardness between the 1960 quality and the same plant effluent quality.

If Q is in thousands of gallons per year, Δhardness is in mg/l, and d is expressed in terms of dollars per thousand gallons per 100 mg/l, the equation will yield penalty costs in dollars per year.

In the foregoing relationship, the appropriate values of Q were derived from various estimates in current literature of such organizations as the Bureau of Reclamation and the Arizona Water Company, and the values of Δhardness were derived from the Project's flow and salt routing model. The value of d was computed from data obtained in interviews with the officials of the specific central softening plant under consideration. The values compared closely with those developed by Howson who estimated the unit cost of central softening to be $0.05 per 1,000 gallons for the first 100 mg/l removed and $0.0125 per 1,000 gallons for each subsequent 100 mg/l removed. In all cases considered by the Project the differences in hardness were well above the 0-100 mg/l range; therefore, a d value of $0.0125 per 1,000 gallons per 100 mg/l hardness removed was used.

If central softening facilities are not available, the cost of building such a plant can be determined. The fixed costs for proposed plants were evaluated using a load factor of two-thirds, an assumed life of 50 years, and interest rates varying between 3-1/2 and 4-1/2 percent. The foregoing values correspond to current design practice and municipal bond interest rates in 1965, respectively. Although operating costs in existing softening plants vary considerably, an average value of $0.0125 per 1,000 gallons per 100 mg/l hardness removed was used in this study.

For this alternative, plants were evaluated for several levels of water supply hardness for which operating costs were calculated. These costs defined several points on a continuous cost-concentration function. The increase in costs over the range of increased hardness concentrations studied was taken as the penalty costs associated with this alternative.

Comparison of Alternatives. The penalty costs associated with each of the alternatives described were calculated for each major municipality in the geographic region studied. A comparison of these penalty costs for the Lower Main Stem study area is presented in Figure 11. Except for the Colorado River Aqueduct service area, the alternative resulting in highest penalty cost was home softening followed by central softening and soap wastage, in that order. This ranking undoubtedly reflects the fact that the soap-wastage method does not account for all the costs incurred. Nevertheless, the soap-wastage method was selected as the measure of municipal water use penalty costs for all municipal entities

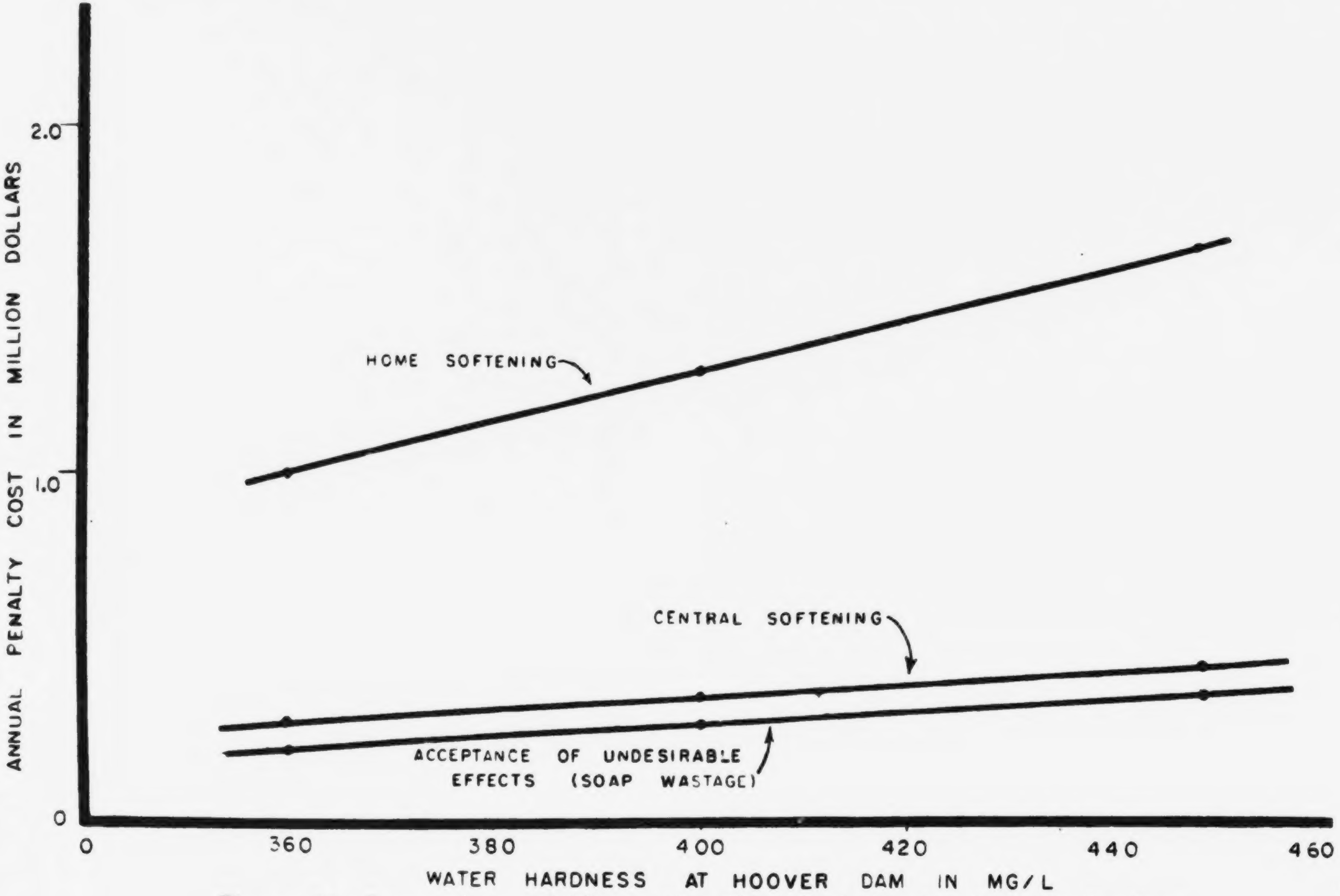


Figure 11. Comparison of Alternative Municipal Penalty Cost Evaluations in the Lower Main Stem Study Area – 1960

except those that actually have central softening plants. These are the Metropolitan Water District of Southern California and the city of Calexico, California, in the Southern California water service area. For these municipalities the central softening method was used to calculate penalty costs.

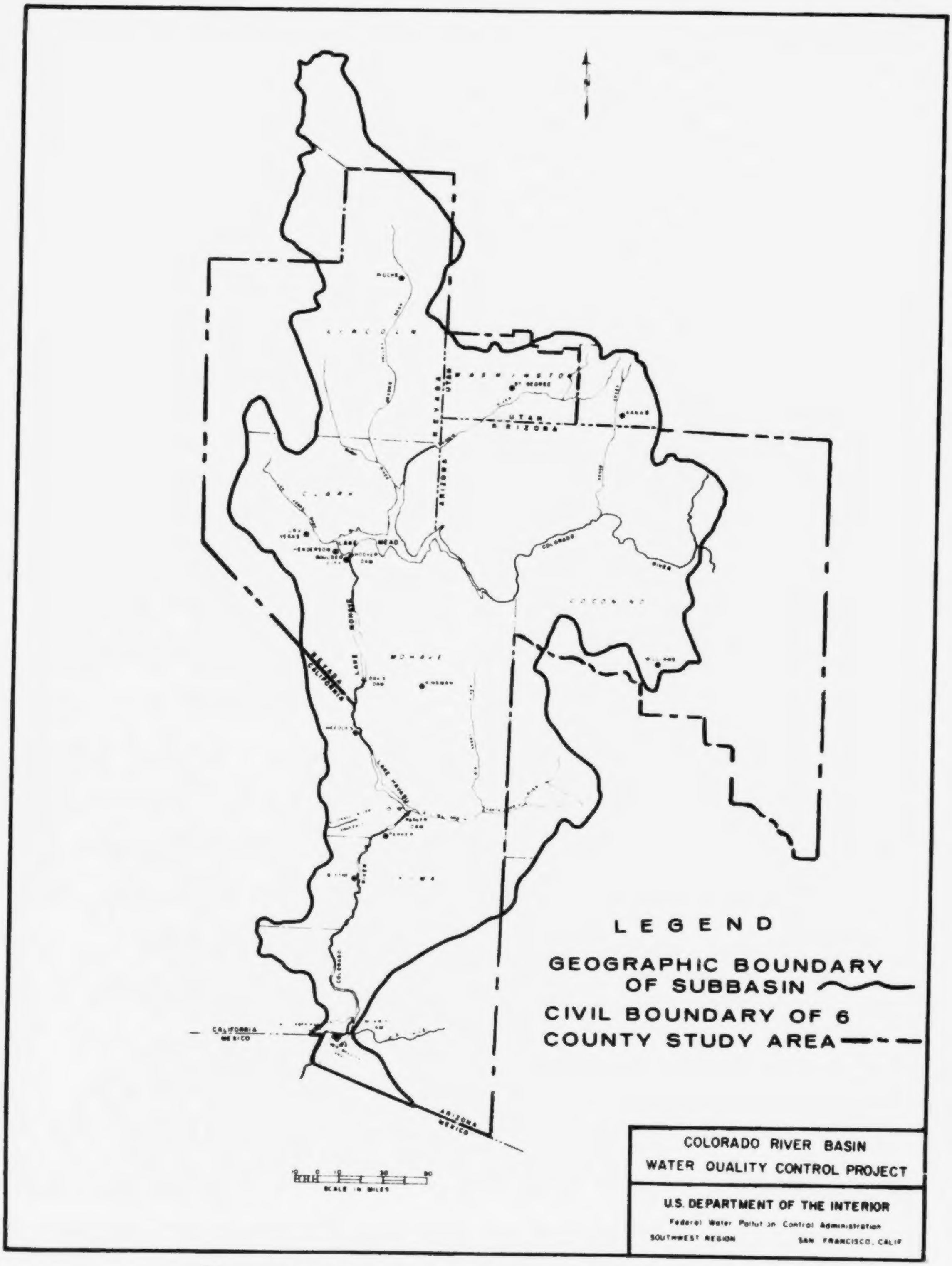
DETERMINATION OF DIRECT PENALTY COSTS

Direct economic impacts of projected changes in mineral quality of the Colorado River were determined for the three primary study areas (Figure 3): (1) Lower Main Stem, (2) Southern California, and (3) Gila. The determination of penalty costs associated with each area is discussed below. A summary of penalty costs for the entire area affected by quality changes begins on page 125.

Lower Main Stem Study Area (Figure 12)

Irrigated Agriculture Users Affected. The irrigation water users assessed penalty costs in the Lower Main Stem study area are all located in Yuma County, Arizona. Yuma County was divided into two areas: (1) Colorado River Indian Reservation, and (2) the remainder of Yuma County. A third area in the Lower Main Stem - including Washington County, Utah; Clark and Lincoln Counties, Nevada; and Coconino and Mohave Counties, Arizona - was studied, but the results of penalty cost assessments proved negligible. Table 16 summarizes data inputs which were assumed for penalty cost assessment for irrigation water uses.

Industrial Users Affected. Industrial water users are defined as all non-agricultural users other than municipalities. They include mining, manufacturing, trades and services, and all utilities. The percent of total use for boiler feed and cooling purposes was projected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UTAH
ARIZONA
CALIFORNIA
MEXICO
WASHINGTON
LINCOLN
CLARK
MOHAVE
COCONINO
YUMA
LAKE MEAD
COLORADO RIVER
LAKE MOHAVE
LAKE HAVASU
LAS VEGAS
HENDERSON
ST GEORGE
KINGMAN
NEEDLES
SCALE IN MILES
LEGEND
GEOGRAPHIC BOUNDARY OF SUBBASIN
CIVIL BOUNDARY OF 6 COUNTY STUDY AREA
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
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Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

Figure 12. Lower Main Stem Study Area

Table 16. Basic Data for Penalty Cost Assessment for Irrigated Agriculture in Lower Main Stem Study Area

Area	Major Crops Grown	Target Year	Acreage	Applied Amount (Acre-Feet)
Colorado River Indian Reservation	Barley, Sorghum Grain, Cotton	1960	30,461	126,500
		1980	84,525	406,600
		2010	101,360	483,000
Remainder of Yuma County		1960	153,085	760,700
Yuma Project	Cotton, Pasture, Alfalfa, Flaxseed, Grapefruit, Oranges, Tangerines, Lemons, Limes	1980	150,368	714,000
		2010	133,500	618,000
Gila Project	Alfalfa Hay, Cotton, Irrigated Pasture, Sorghums, Lemons, Limes, Oranges, Tangerines, Cantaloupes, Lettuce			

to remain at the 1960 level for all sectors except electrical energy which is the major heavy water use in the Lower Main Stem study area. Although recent trends indicate that this percentage is decreasing,(40, 41) it was felt that the majority of industrial users would not convert to more costly high tolerant systems. These users would, therefore, be forced to maintain the present relative percentage of boiler feed and cooling water usage. For the electrical energy sector, it was assumed that present volume of cooling and boiler feed water use by sensitive systems would remain constant over time although total use was projected to increase. This assumption resulted in projected percentages of 90, 11, and 3 for 1960, 1980, and 2010, respectively, for sensitive-system use relative to total intake requirement.

The intakes for industrial users of Colorado River water are located throughout the length of the study area. However, more than 75 percent of all industrial water consumed in the Lower Main Stem study area is diverted from Lake Mead to the Henderson, Nevada, industrial complex Thus, it was assumed that all industrial diversions occurred at Lake Mead The target year mineral qualities at Lake Mead were, therefore, used as intake qualities for all industries in the Lower Main Stem study area. The relative magnitude of penalty costs did not warrant further refinement.

Municipal Users Affected. Five municipalities in the Lower Main Stem area will be affected by changes in the quality of Colorado River water. The target year populations served by Colorado River water (not necessarily the total populations) and the target year water qualities (hardness) at the respective points of diversion from the river are shown in Table 17.

Table 17. Municipalities Served by Colorado River Water in the Lower Main Stem Study Area

Municipality	Population Served[a] 1960	1980[b]	2010[b]	Hardness ($CaCO_3$)[c] (mg/l) 1960	1980	2010
Las Vegas, Nevada	42,500	141,000	272,000	345	420	460
Henderson, Nevada	17,000	39,000	75,000	345	420	460
Boulder City, Nevada	4,300	12,700	24,000	345	420	460
Parker, Arizona	1,500	4,000	7,000	340	415	460
Yuma, Arizona	30,000	58,000	101,000	370	485	540

---

a/ Population served by Colorado River water, not necessarily the total population.
b/ Population projections are Leasure's median projections.(38)
c/ Intake quality as developed in Project's salt and flow routing model.

Results of Analyses. Each individual user's water quality is directly related to the water quality at Hoover Dam, as shown in Table 17. As indicated in Chapter III, penalty costs incurred by each user were plotted versus Hoover Dam water qualities. Hoover Dam serves as a convenient reference point and is the major control structure on the river system below which all significant penalty costs are incurred In fact all user intakes in the three study areas are located at or below Hoover Dam. The results of the direct penalty cost analyses are summarized in Table 18.

Table 18. Summary of Direct Penalty Costs in the Lower Main Stem Study Area

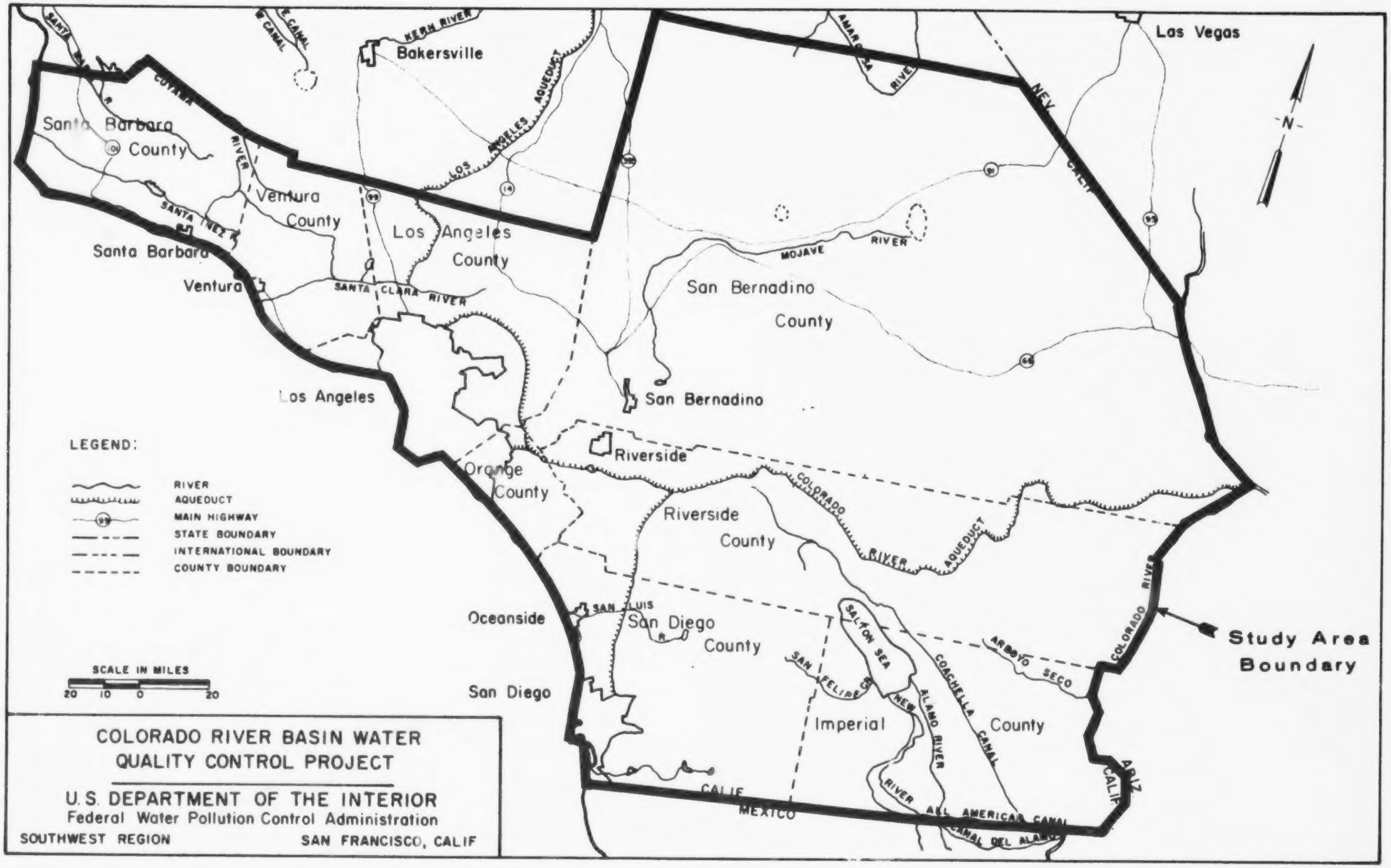
Type User	Target Years 1980 ($1000 annually)	2010
Irrigated Agriculture	1,096.5	2,423.8
Municipal	275.0	779.0
Industrial	106.7	410.2
TOTAL	1,478.2	3,613.0

Southern California Study Area (Figure 13)

For convenience, all California lands receiving Colorado River water were included in this study area. The area is divided into three parts: one served by the Colorado River Aqueduct with diversion point at Parker Dam, one served by the All American Canal which originates at Imperial Dam, and the other comprising California lands along the Colorado River with varying diversion points. The total study area is shown in Figure 13, and the water distribution systems are shown more clearly in Figure 14.

Colorado River Aqueduct Service Area. A substantial blending of northern California water with Colorado River Aqueduct (CRA) water is expected by 1980. An increasing supply of northern California water of high quality will be delivered via the Foothill Feeder to MWD's present treatment plants at La Verne and Yorbe Linda, and probably also to a third plant near Pasadena proposed for construction in the 1980's.

An analysis of the possible effect on MWD water blended with northern California water was made assuming that the CAP delivery schedule is met. The results are summarized graphically in Figure 15. The upper curve shows that, based upon projected Colorado River quality degradation, the quality of MWD supply will continue degrading until 1971 when deliveries of northern California water are scheduled to begin and, thereafter, will improve rapidly to 350 mg/l by 1979, the date postulated for the beginning operation of the CAP. Assuming that the full load of the CAP is realized immediately, salinity levels in the blended MWD supply should drop to about 380 mg/l in the following year. Thereafter, over the next 35 years, there will be a long decline as gradually increasing amounts of high quality northern California water are brought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SANTA CLARA RIVER
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Riverside
Orange County
Riverside County
COLORADO RIVER AQUEDUCT
Oceanside
SAN LUIS
San Diego County
San Diego
SALTON SEA
SAN FELIPE
NEW
ALAMO RIVER
COACHELLA CANAL
Imperial County
ARROYO SECO
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Study Area Boundary
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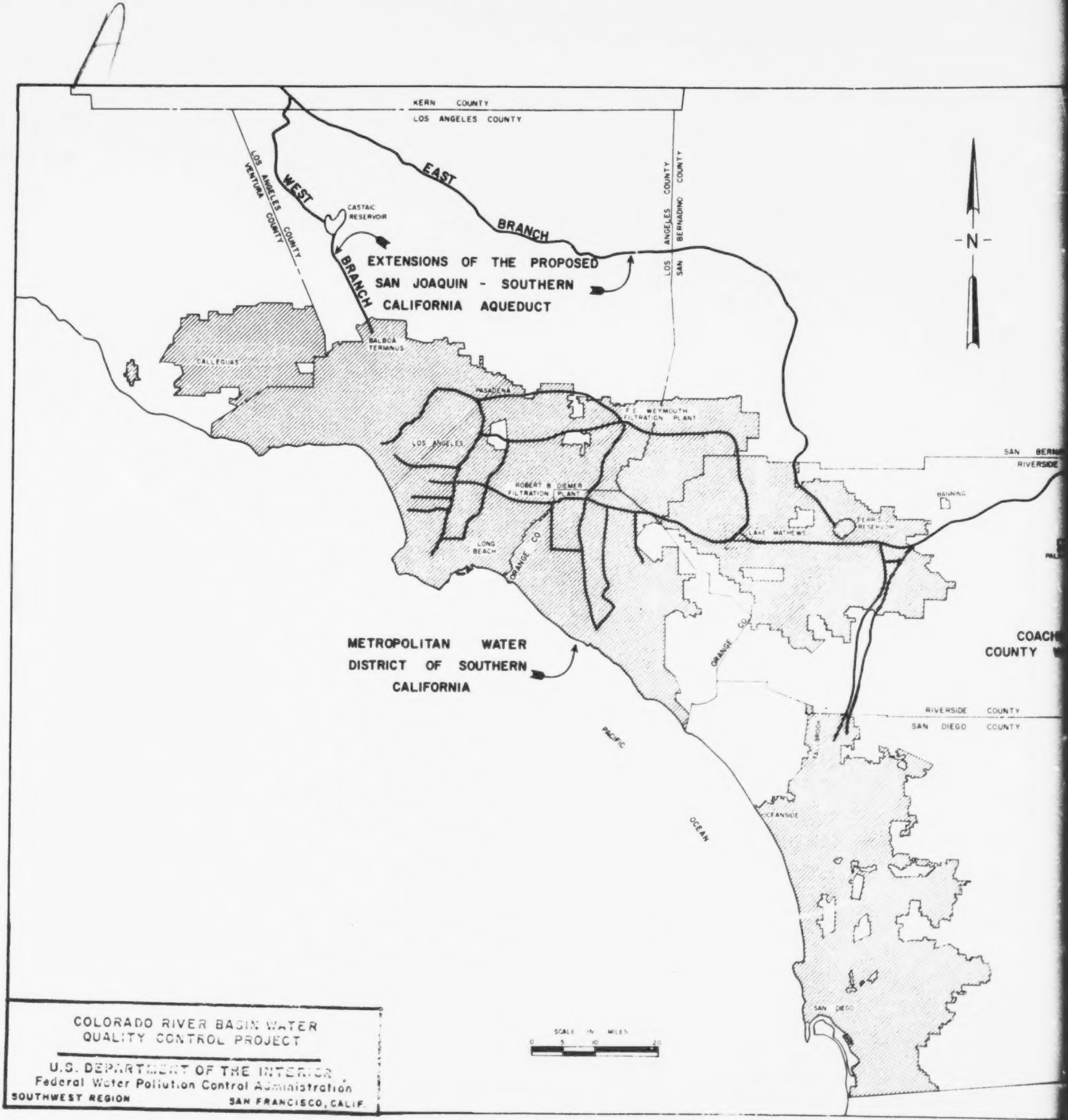
SOUTHWEST REGION
SAN FRANCISCO, CALIF

Figure 13. Southern California Study Area


KERN COUNTY
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SAN BERNARDINO COUNTY
WEST BRANCH
EAST BRANCH
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PASADENA
F.E. WEYMOUTH FILTRATION PLANT
LOS ANGELES
ROBERT B. DIEMER FILTRATION PLANT
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ORANGE CO
LAKE MATHEWS
BANNING
SAN BERN
RIVERSIDE
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA
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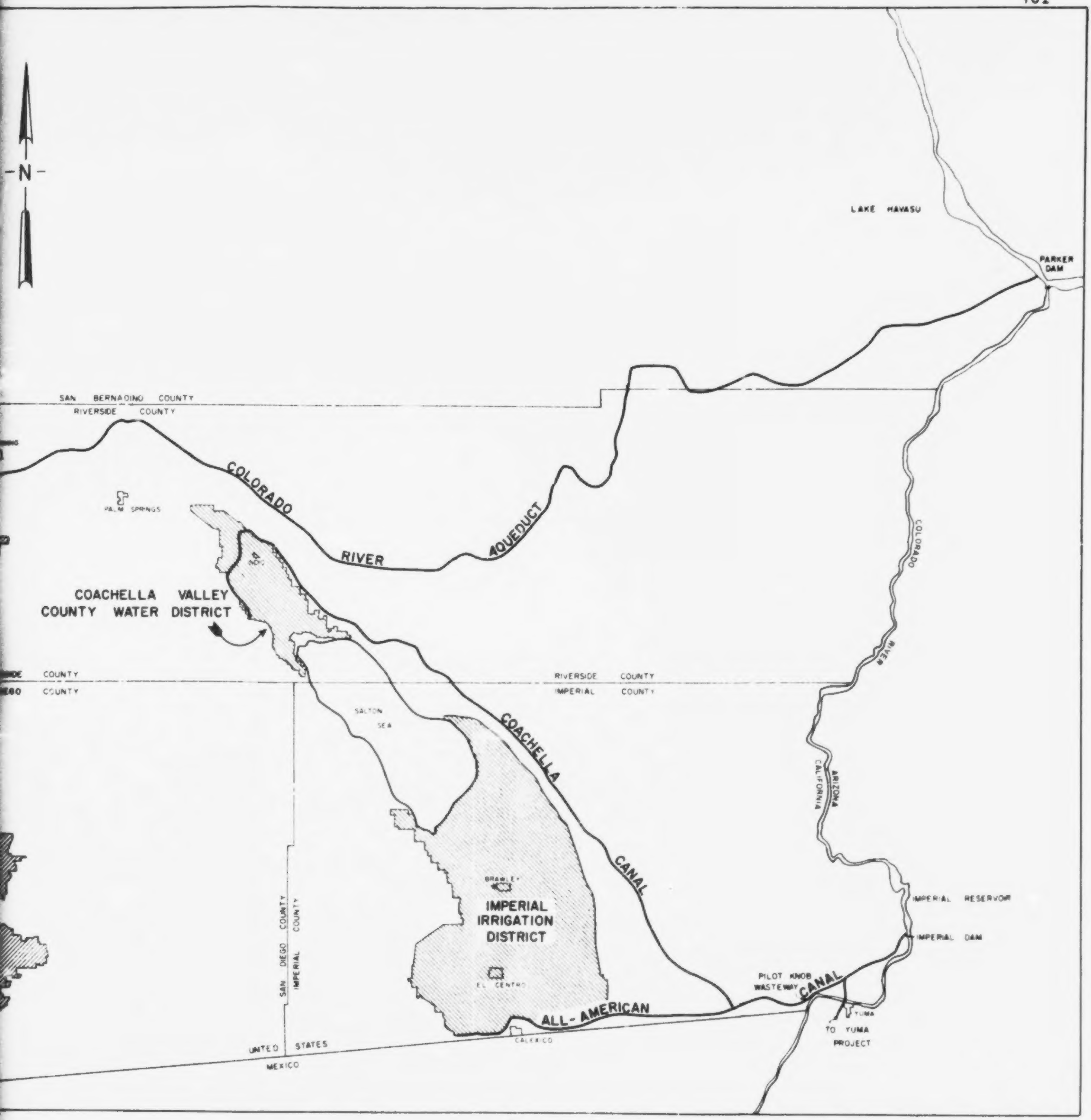
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COLORADO RIVER
RIVERSIDE COUNTY
SAN DIEGO COUNTY
RIVERSIDE COUNTY
IMPERIAL COUNTY
SALTON SEA
COACHELLA CANAL
CALIFORNIA
ARIZONA
BRAWLEY
IMPERIAL IRRIGATION DISTRICT
SAN DIEGO COUNTY
IMPERIAL COUNTY
IMPERIAL RESERVOIR
IMPERIAL DAM
EL CENTRO
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Figure 14. Southern California Water Service Area

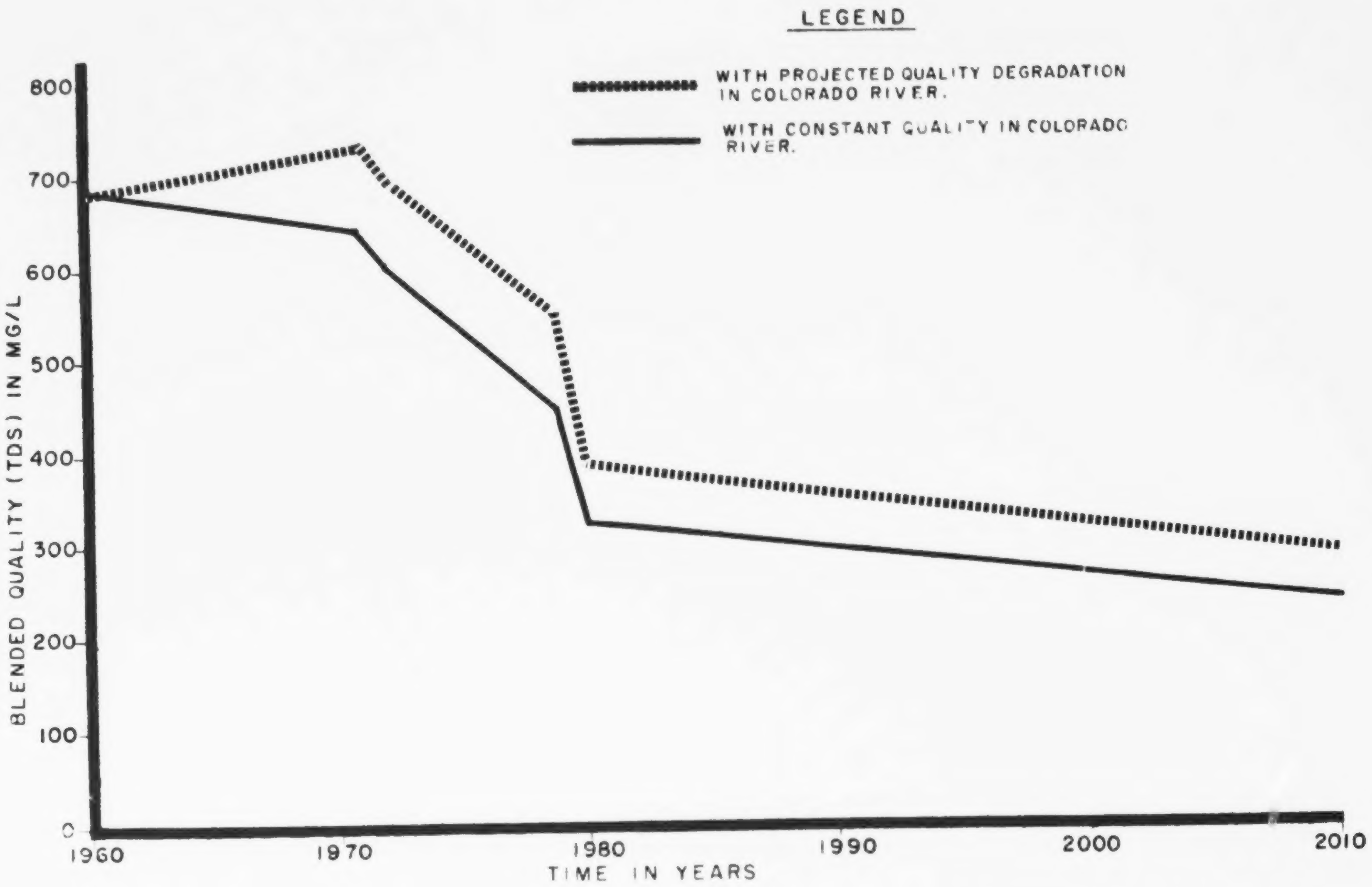

Figure 15. Quality of the Metropolitan Water District Blended Supply Composed of Colorado River and Feather River Water

in. In the year 2010 the quality of the blended MWD supply will be about 290 mg/l if quality degradation of Colorado River water continues at the projected rate.

The lower curve shows the consequences of an unchanging quality level in the Colorado River portion of the supply with total dissolved solids maintained constant at the 1960 value of 684 mg/l at Parker Dam. Therefore, use of Colorado River water affects the blended MWD supplies by 55 mg/l (325 to 380) in 1980 and by 50 mg/l (240 to 290) in 2010. A synoptic tabulation of anticipated changes in salinity of the MWD blended supply is shown in Table 19.

Table 19. Present and Projected Mineral Quality of Metropolitan Water District Blended Water Deliveries

Year	Colorado River Supply		Feather River Supply		Blended Supply	
	Volume (1000 AF/Yr)	TDS (mg/l)	Volume (1000 AF/Yr)	TDS (mg/l)	Quality (mg/l)	TDS[a] (mg/l)
1960	817	684			684	684
1971	1,105	784	95	160	740	640
1972	1,120	793	200	160	700	600
1979	1,212	857	956	160	550	450
1980	550	866	1,064	160	380	325
2010	550	985	2,635	160	290	240

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a/ Blended quality assuming constant Colorado River salinity of 684 mg/l.

Agricultural Users Affected. The MWD provides an agricultural water supply to several constituent members. At the present time, the most prominent agricultural use member - the San Diego County Water Authority - distributes water to four irrigation districts in the western part of the county, and this pattern is expected to continue. The relationship between the total agricultural use of

MWD water and the agricultural use of MWD water supplied to the San Diego County Water Authority is shown in Table 20.

Table 20. Present and Projected Use of Metropolitan Water District Water for Irrigated Agriculture

Year	Total MWD Use[a] (Acre-Feet)	San Diego County Use[a] (Acre-Feet)
1960	119,160	39,700
1965	152,756	69,069
1980	161,000	110,000
2010	130,000	130,000

[a] Information obtained from personal contact with MWD personnel.

Three assumptions were made in order to evaluate the effects of changes in the quality of Colorado River water on the MWD users. The first assumption was that the cropping pattern of western San Diego County is representative of the cropping pattern in the total area served by the MWD. This assumption seems reasonable since the portion of MWD agricultural water used in San Diego County will increase until the year 2010 when all MWD agricultural water will be used in that area. The second assumption was that by the year 1980 the MWD deliveries would be a blend of 485,000 AF of Colorado River (684 mg/l) and 1.5 million AF of Feather River water (160 mg/l).[1] The third assumption was that the blended irrigation water would be diluted uniformly by an average annual effective local rainfall of nine inches[1] and that this water would be consumed by crops and other vegetation. (It should be recognized that the economic effects are dampened considerably by the last two assumptions.)

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[1] The blend of northern California and Colorado River water is based upon published delivery schedules assuming that CAP will be completed by 1980. MWD personnel have informed the Project that present plans are to divert 65,000 AF from the CRA directly to agricultural users in the San Diego area before any blending with northern California water. Therefore, the amount of Colorado River water which will be blended has been reduced from 550,000 AF to 485,000 AF.

Based upon the assumptions stated above, data were developed for use in calculating the direct economic penalty costs to the irrigation water users served by the MWD. These data are summarized in Table 21.

Table 21. Present and Projected Data Used in Evaluating the Direct Penalty Costs to Irrigation Water Users Served by the Metropolitan Water District

Target Year	Acreage (AC)	Amount Irrigation Water Applied (AF)	Effective Rainfall (AF)	Total Water Applied (AF)	Blended Quality (TDS) (mg/l)
1960	62,900	120,000	50,000	170,000	--
1980	83,100	160,000	66,000	226,000	409
2010	66,700	130,000	53,000	183,000	452

Industrial Users Affected. The Colorado River Aqueduct delivers water to the Metropolitan Water District of Southern California which, in turn, serves water users in a six-county area stretching from Ventura County to San Diego County (Figure 14).

Present total water use for the Southern California study areas was determined from available published data. Data for the MWD, which is the only entity served by the Colorado River Aqueduct, was obtained from State of California publications.(34) A summary of these data for the six-county area served by MWD is given in Table 22. Bulletin 78, California Department of Water Resources,(19) contains information indicating that 87 percent of the six-county area is served by MWD; however, only 28 percent of the water delivered by MWD is supplied by the Colorado River.[1] Therefore, the present total amount of industrial water supplied to Southern California via the CRA was estimated to be: (0.87)(0.28)(290,000) = 71,000 AF.

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[1] "Effective rainfall" is defined as rainfall that is not lost by runoff during a storm and is not lost by evaporation from the ground surface after a storm. During the seasons 1932-1957, 15 inches of seasonal rainfall was exceeded only five times at Pomona, an area with higher rainfall than the study area. There were only three years in 25 that were likely to produce any leaching of lands under winter crops.(19)

Future intake requirements for the CRA were extrapolated from estimates of the probable ultimate industrial development and the ultimate delivery requirements per irrigated acre. An alternate calculation relating industrial use to projected urban demand produced a second approximation of intake requirements. From these two estimates, a total intake requirement of 825,000 AF was established for the year 2010 and 500,000 AF for the year 1980. Based upon the assumptions: (1) published delivery schedules for northern California water will be met; (2) Colorado River water will be delivered in accordance with the authorized schedule for the Central Arizona Project; (3) two-thirds of all water use is for cooling and boiler feed purposes;(5) and (4) industry will use local and imported waters in proportion to their general availability in the area, it was estimated that 215,000 AF of Colorado River water would be used for cooling and boiler feed

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[1] Records of MWD for water year 1962-63.

Table 22. Water Use by Manufacturing Industry in the Six Counties of the Metropolitan Water District of Southern California, 1957-1959

	Petrol. Ref	Food	Chem. & Allied	Paper	Stone, Clay & Glass	Fab. Metals	Transp. Eqpt.	Prim. Metals	Wood (Exc. Furn.)	Sub-Totals	% of County Totals	County Totals
			(Acre-Feet per year x 1000)									
SIC No.	29	20	28	26	32	34	37	33	24			
Los Angeles	75.3	32.4	22.0	19.6	7.2	20.6	16.3	5.6	0.5	199.5	89	224.2
Orange	2.6	4.8	2.0	1.1	0.1	0.8	0.9	0.5	0.4	13.2	74	17.9
San Diego	9.2	3.7	1.1	0.0	0.2	0.3	2.5	0.1	0.1	17.2	93	18.5
San Bernardino	0.2	2.0	0.3	0.0	5.6	0.1	0.1	6.5	1.4	16.2	93	17.5
Riverside	1.8	1.2	0.0	0.1	2.9	0.1	0.5	0.4	0.0	7.0	96	7.3
Ventura	0.4	1.7	0.7	0.6	0.2	0.0	0.0	0.0	0.4	4.0	92	4.4
											Grand Total	289.8
											or Approximately	290

purposes within the MWD in 1980 and 418,000 AF would be used for these purposes in 2010.

Incremental water requirements were calculated by the mathematical relationship discussed in the section entitled, "Methods of Penalty Cost Evaluation." The mineral quality of water delivered to industrial uses was assumed to deteriorate from 360 to 400 mg/l in 1980 and from 240 to 300 mg/l in 2010. Based on an average tolerance of 2,200 mg/l for sensitive industrial systems in the Colorado River Basin, additional water required to offset quality deterioration was estimated to be 455 AF/yr in 1980 and 735 AF/yr in 2010.

A unit cost of $35 per acre-foot was used to calculate the penalty cost associated with makeup water requirements in the MWD. Incremental treatment costs were derived from an industrial water-use survey made in 1959 by the National Aluminate Corporation.(42) Unit costs for treating cooling water generally ranged between three and seven cents per 1,000 gallons for internal treatment in Southern California with a bias toward the higher figure. The latter figure was used except where a lower cost was known to prevail.

A summary of pertinent data used to evaluate industrial penalty costs in the Southern California area is presented in Table 23.

Table 23. Projected Industrial Water Requirements for the Metropolitan Water District

Type of Use	1960 (AF)	1980 (AF)	2010 (AF)
Cooling Requirement	46,000	187,000	362,000
Boiler Feed Requirement	6,000	28,000	56,000

Municipal Users Affected. The MWD has two large water treatment plants. The older F. E. Weymouth Filtration and Softening Plant located near La Verne has a capacity of 400 mgd. Softening is done by a cation-exchange process. The large-scale and integrated nature of the operation (the district itself produces much of the sodium chloride needed for regeneration of the cation exchange materials) permits softening at a very low cost of less than 1-1/2 cents per 1,000 gallons. A new water treatment facility, the Robert B. Diemer Plant located near the community of Yorbe Linda, was dedicated in 1964. It has a filtration capacity of 200 mgd, but does not have any water-softening facilities.

Of the 550,000 AF/year assumed to be diverted from Lake Havasu in 1980 and 2010, the MWD municipal users are assessed the costs of softening 400,000 AF/year in both target years. The remaining unsoftened volumes are assumed filtered at the Diemer Plant and then blended with northern California water. Of these remaining volumes, it was assumed that agriculture would use 95,000 AF/year and 65,000 AF/year in 1980 and 2010, respectively. Only the softening expense makes up the penalty costs; the cost of filtering is, of course, not included.

Penalty cost assessments were based on central softening treatment cost of $0.125/1,000 gal/100 mg/l hardness removed. The present and projected municipal use of MWD water is shown in Table 24.

All American Canal Service Area.

Agricultural Users Affected. The All American Canal conveys water diverted at Imperial Dam to Imperial County and the Coachella

Table 24. Present and Projected Municipal Use of Metropolitan Water District Water

Target Year	Volume (AF)
1960	442,000
1980	400,000
2010	400,000

Valley Irrigation District. The present and projected acreages, amounts of applied water, and major crops grown in these areas are shown in Table 25.

Industrial Users Affected. Present industrial water intake requirements for the All American Canal service area were derived from existing data. Future demand was assumed to grow in strict proportion to sales of manufactured products. Based upon this assumption and considering that the relative ratio of boiler feed and cooling water use to total intake would remain constant, estimates of 125 AF/year in 1980 and 380 AF/year in 2010 were derived. Table 26 shows present and future intake water requirements. In addition to the amounts shown in the table, approximately 433 AF of water were consumed in steam-electric power generation in 1964. The annual projected intake requirements for this purpose are 860 AF in 1980 and 1,740 AF in 2010.

Industries served by the All American Canal use Colorado River water exclusively so that there are no effects caused by dilution water from other sources. The water quality at Imperial Dam was used as the intake quality in all cases for industries in this area. The significant industrial supply qualities for diversion

Table 25. Basic Data for Penalty Cost Assessment to Irrigated Agriculture, All American Canal Users

Area	Major Crops Grown	Target Year	Acreage	Water Applied (Acre-Feet)
Imperial County	Alfalfa, Barley, Vegetables	1960	489,716	2,426,700
		1980	560,000	2,704,000
		2010	529,000	2,552,000
Coachella Valley County Water District	Carrots, Grapes, and Cotton	1960	44,671	284,000
		1980	54,800	351,750
		2010	54,500	351,000

Table 26. Summary of Water Data Used for Industrial Penalty Cost Assessment in Imperial County, California

Year	Cooling (A-F/yr)	Boiler Feed (A-F/yr)	Process (A-F/yr)	Other (A-F/yr)	Total (A-F/yr)	Intake Quality (mg/l)
1960[a]	1,927	192	1,706	526	4,351	759
1965	2,670	270	2,360	560	5,860	---
1980	5,290	530	4,680	1,100	11,600[b]	1,056
2010	10,800	1,070	9,520	2,250	23,600[b]	1,223

---

[a] Based on 1957-1959 period.

[b] Values rounded.

and delivery points are summarized in Table 26.

Municipal Users Affected. As mentioned before, several communities in Imperial County get their water supply from the Colorado River via the All American Canal distribution system. These communities, listed in order of their population, are El Centro, Brawley, Calexico, Holtville, Imperial, Calipatria, Westmorland, and Niland. The present and projected populations of these communities are shown in Table 27.

Table 27. Present and Projected Populations of Imperial County Communities

Towns	1960	1980	2010
El Centro	18,300	25,800	45,400
Brawley	13,000	14,300	16,800
Calexico	8,900	12,600	22,300
All Others	11,200	15,000	22,500
Total	51,400	67,700	107,000

Only Calexico practices softening in a central municipal plant. Privately owned or rented water softeners are widely used in other communities because of the hardness of the supply (approximately 385 mg/l). A survey conducted in December of 1964 among several commercial water softening services and sales outlets indicated that between 2,500 and 3,000 water softeners are in use in Imperial County. A reasonable estimate of the total population using softened water in the valley would be 19,000 (9,000 in Calexico and 10,000 in the remaining communities). This is about 37 percent of the urban population. All of this group would be affected by rising costs of water softening if the hardness of the supply should increase. The remaining 63 percent of the population would also be injured, not by rising expense of treatment but rather by the necessity for heavier consumption of soap, etc., as previously described.

Other California Users. There are other users of Colorado River water located in California that are not served either by the MWD system or the All American Canal. These users, located along the Colorado River, are the Palo Verde Irrigation District and the communities of Needles and Blythe.

Agricultural Users Affected. Irrigation water for the Palo Verde district is diverted from the Palo Verde Diversion Dam located upstream from Blythe, California. The present and projected acreage of principal crops grown and amounts of applied water in the district are shown in Table 28.

Table 28. Principal Crops Grown, Present and Projected Irrigation Acreages, and Amounts of Applied Water in the Palo Verde Irrigation District

Principal Crops Grown	Target Year	Irrigated Acreage	Applied Irrigation Water (Acre-Feet)
Alfalfa, Cotton, Barley	1960	78,735	376,600
	1980	111,800	541,400
	2010	121,000	595,400

Municipal Users Affected. The towns of Needles and Blythe are located in California along the Colorado River and both get their municipal water supply from the river. For purposes of penalty cost assessment, they are included in the Southern California water service area. The present and projected populations of these two towns are shown in Table 29.

Table 29. Present and Projected Populations of Needles and Blythe, California

Town	1960	1980	2010
Needles	6,080	10,600	14,000
Blythe	6,000	13,900	18,500

Results of Analyses. The results of the penalty cost analyses for the MWD service area, the All American Canal service area, the "other California" area, and the total Southern California study area are summarized in Table 30.

Gila Study Area (Figure 16)

The Gila study area is defined by counties. It includes Maricopa, Pima, Pinal, Santa Cruz, Cochise, Graham, Greenlee, Gila, Yavapai, and Catron Counties.

Agricultural Users Affected In order to evaluate the effect of salinity in the Central Arizona Project area, it was necessary to make four assumptions: (1) All Colorado River water deliveries will be used for irrigated agriculture, the least sensitive of all users; (2) there will be uniform mixing of agricultural supplies from all sources (ground, surface, and CAP deliveries); (3) the quality of ground water in the CAP area is the median or 50 percentile average quality of all ground water presently used; and (4) the quality of surface and ground water presently used will not change in time, and only CAP water delivered from the Colorado River will change.

Each of the above assumptions was designed to produce conservative

Table 30. Summary of Direct Penalty Costs Incurred by All Southern California Users of Colorado River Water

Type Users	1980				2010			
	Colorado River Aqueduct	All-American Canal	Other Calif.	Southern Calif. Study Area Total	Colorado River Aqueduct	All-American Canal	Other Calif.	Southern Calif. Study Area Total
		($1,000 annually)				($1,000 annually)		
Irrigated Agriculture	484.9	3,704.3	427.8	4,617.0	751.9	8,371.7	948.5	10,072.3
Industrial	49.4	6.8	---	56.2	79.7	22.9	---	102.6
Municipal	1,220.0	100.0	27.0	1,347.0	1,950.0	233.0	56.0	2,239.0
TOTAL	1,754.3	3,811.1	454.8	6,020.2	2,781.6	8,627.6	1,004.5	12,413.9

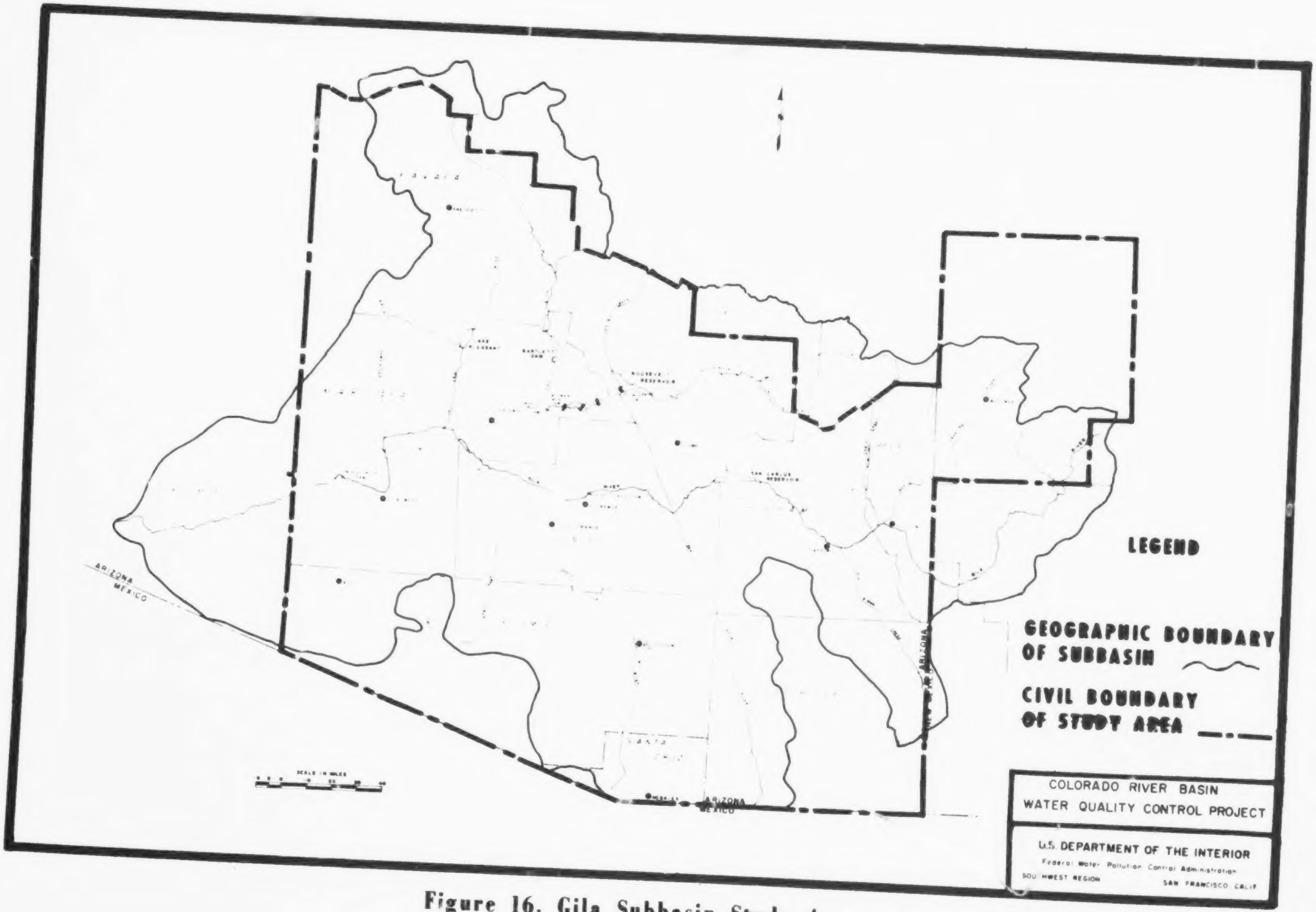
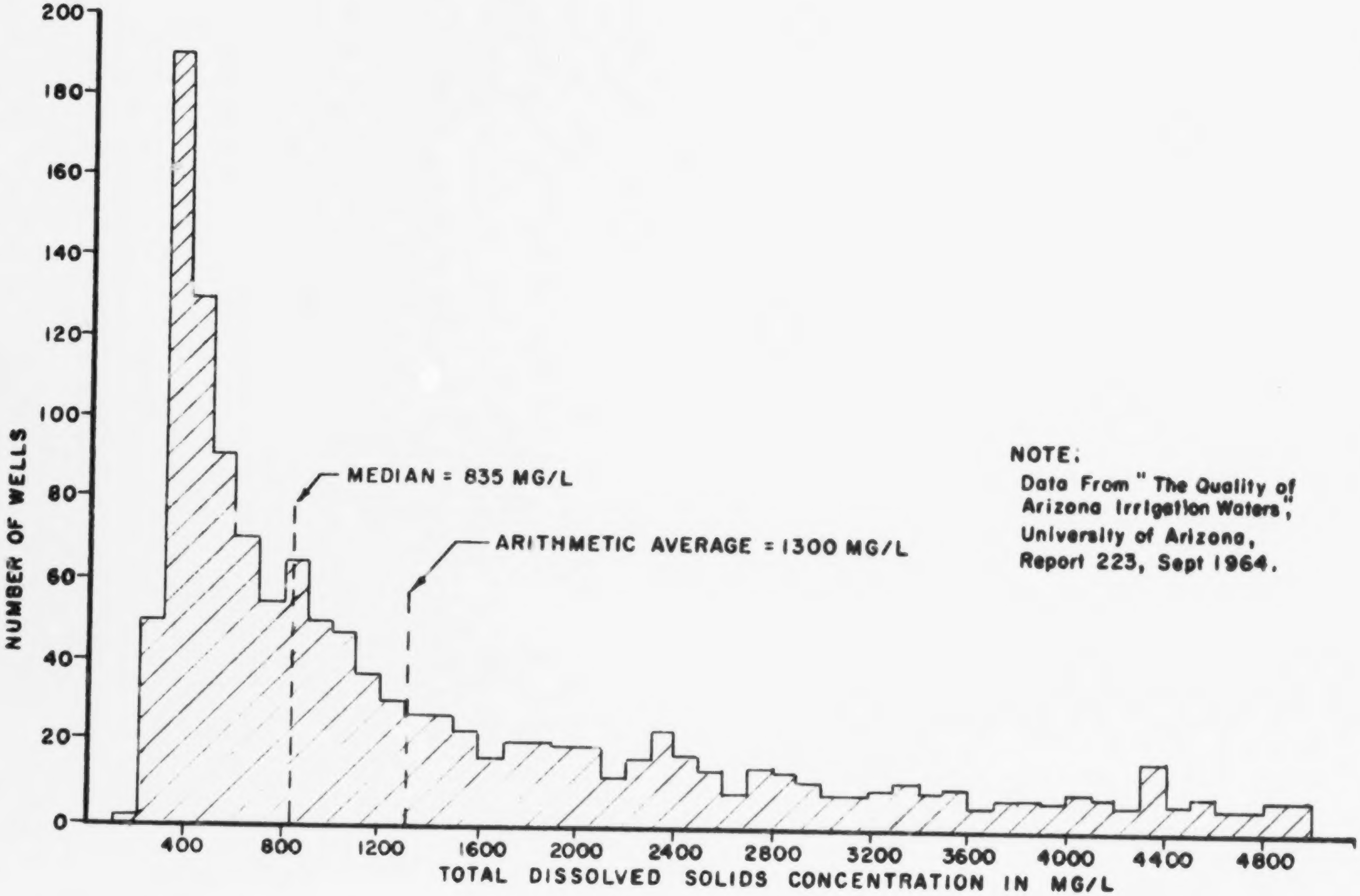

LEGEND
GEOGRAPHIC BOUNDARY OF SUBBASIN
CIVIL BOUNDARY OF STUDY AREA
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF.
SCALE IN MILES
ARIZONA
MEXICO
ARIZONA
NEW MEXICO
SAN CARLOS RESERVOIR
ROOSEVELT RESERVOIR
SANTA CRUZ

Figure 16. Gila Subbasin Study Area

estimates of total penalty costs. The assumptions were necessary because present and projected data were not adequate and, in some instances, not available. The first assumption implies that good quality ground water now used for irrigation will be exchanged for CAP water allocated to municipal use. Refining the second assumption would require operational data and projections of use (in many cases not available) from each individual water company, entailing a long and expensive survey and analysis. In the third assumption, quality of ground water used for irrigation was estimated at a median TDS concentration of 835 mg/l (Figure 17). A more representative flow-weighted average could have been computed if the volume of water and quality data were available for each well. The arithmetic average TDS concentrations for the wells is 1,300 mg/l (Figure 17). The fourth assumption was based on information obtained from knowledgeable persons in the Phoenix-Tucson area who indicated that separate analyses for each ground water basin would be required to identify quality trends. Preliminary attempts to identify quality trends using limited data were unsuccessful, primarily because ground water quality in the CAP area varies widely in composition and concentration both horizontally and vertically. This variance is not only related to the quality of the recharge waters, but also to the chemical changes occurring within the ground water mass.

The present (1960) and projected irrigated acreages were defined for the Gila study area by economic sector. From the aqueduct delivery and turnout points, it appeared that substantially all of Maricopa and Pinal Counties and portions of Pima County would receive CAP water or return flows. It was assumed that no area south of Tucson would be



NOTE:
Data From " The Quality of Arizona Irrigation Waters", University of Arizona, Report 223, Sept 1964.

Figure 17. Mineral Quality of Ground Water Used for Irrigation in the Central Arizona Project Area

affected and that areas outside the Santa Cruz River Valley proper north of Tucson would not be affected. Thus, about 50 percent of the irrigated area of Pima County would be influenced. Therefore, all irrigated lands in Maricopa and Pinal Counties and half of those in Pima County were assessed agricultural salinity penalty costs.

A decline in irrigated acreage is projected for every county in the study area. Since the irrigated area affected by the CAP accounts for 81.5 percent of all acreage in the study area in 1960, it was assumed that the CAP area acreages would decrease in proportion to the total reduction in subbasin acreage. Water requirements for the CAP are shown in Table 31.

Table 31. Present and Projected Water Required for Agriculture in the Central Arizona Project Area

Year	Amount (1000 AF/Yr)
1960	3,482
1980	3,286
2010	2,923

The sources from which the water requirements will be met are shown in Table 32. The surface supply quality was estimated to be the average of the 1914-1958 hydrologic period as shown in Table 33.

Estimating an average ground water quality is subject to uncertainty due in part to a lack of both flow and quality data. Therefore, a statistical analysis of domestic and of irrigation ground water quality was made, based on data from two University of Arizona publications. (43, 44) The affected ground water areas were delineated as indicated

Table 32. Present and Projected Sources of Water for Irrigation in the CAP Area

Year	Sources			Total
	Surface	Ground (1,000 A.F./Yr.)	CAP	
1960	723[a]	2,759	---	3,482
1980	723	1,606	957[b]	3,286
2010	723	1,627	573[b]	2,923

---

a/ Farm deliveries from diversion of 1,096,000 acre-feet.

b/ Applied CAP water assuming a 70 percent delivery efficiency to farm headgates.

Table 33. Quantity and Quality of Surface Waters Entering the CAP Area[a]

Source	Volume	TDS Quality (mg/l)
Agua Fria River at Lake Pleasant	100,600	210
Verde River at Bartlett Dam	454,800	240
Salt River at Stewart Dam	626,000	810
Gila River at Kelvin	356,000	600
Volume Weighted Average for all Supplies	---	555

---

a/ From Colorado River Basin Water Quality Control Project routing model.

in Figure 18. The distribution of mineral quality for wells in these areas is shown in Figure 17. The median TDS concentration is 835 mg/l while the flow-weighted mean is about 1,300 mg/l The median and weighted mean for the domestic wells are 480 mg/l and 700 mg/l, respectively. It was assumed that the TDS concentration of ground water used for agriculture would be 835 mg/l in each target year

Imported water is the third supply source. Mineral quality at Parker Dam, the diversion point, was projected by the routing model to be 866 mg/l in 1980 and 985 mg/l in 2010. Mineral quality at the point of delivery was estimated by computing the evaporation losses (concentrating effects) incurred in transit. These losses were determined by subtracting the seepage losses from the total losses. Bureau of Reclamation estimates of total losses on the order of 10 percent of total volume were used. The dimensions of the proposed aqueduct and the coefficient of permeability of the concrete lining were obtained from Bureau of Reclamation reports and were used in computing the seepage losses. Based on these calculations, the qualities at the point of delivery were estimated to be 920 mg/l and 1,010 mg/l in 1980 and 2010, respectively.

The penalty cost assessment was based on the schedule of deliveries presented in the 1967 Hearings on the Central Arizona Project before the U. S. Senate Subcommittee on Water and Power

Major crops grown, irrigated acreages, and the amount and quality of applied irrigation water in 1960 and projections for 1980 and 2010 are shown in Table 34.

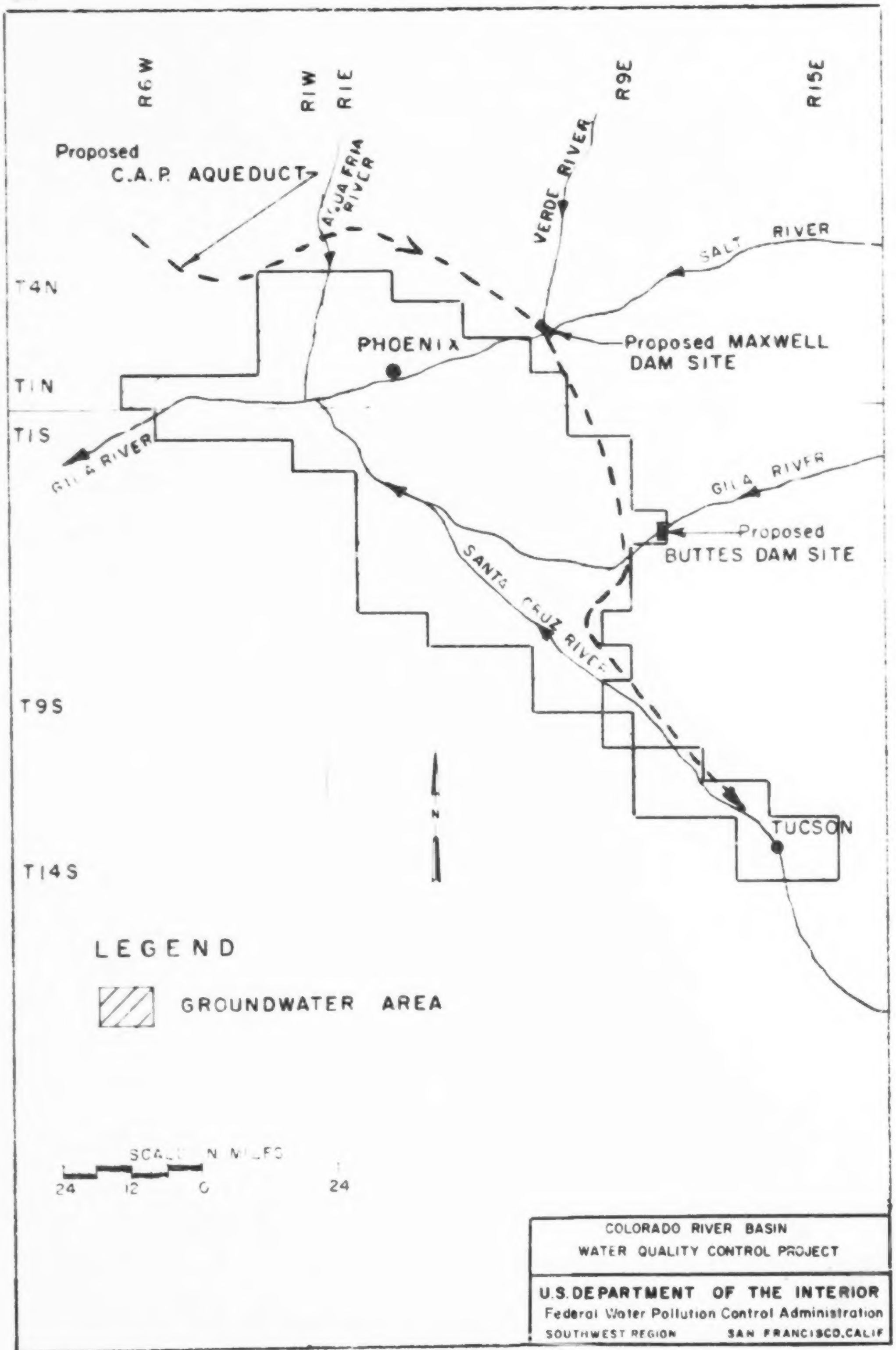

R6W
R1W
R1E
R9E
R15E
Proposed
C.A.P. AQUEDUCT
AGUA FRIA RIVER
VERDE RIVER
SALT RIVER
T4N
PHOENIX
Proposed MAXWELL DAM SITE
T1N
T1S
GILA RIVER
GILA RIVER
Proposed
BUTTES DAM SITE
SANTA CRUZ RIVER
T9S
N
TUCSON
T14S
LEGEND
GROUNDWATER AREA
SCALE IN MILES
24
12
0
24
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
SOUTHWEST REGION
SAN FRANCISCO, CALIF

Figure 18. Location of Major Groundwater Areas in the Central Arizona Project Area

Table 34. Major Crops Grown, Present and Projected Irrigated Acreages, and Amounts and Quality of Applied Irrigation Water in the Central Arizona Project Area

Major Crops Grown	Year	Acreage	Applied Amount (AF)	Blended Quality (TDS) (mg/l)
Cotton, alfalfa, barley	1960	835,700	3,482,000	777
	1980	771,000	3,286,000	796
	2010	630,000	2,923,000	800

Existing surface and ground water supplies made up the 1960 requirement since there was no Colorado River water used in that year. The effect of the CAP is shown from 1980 to 2010. There is no salinity penalty cost in 1980 - the assumed water delivery date for the CAP

Industrial and Municipal Users Affected. According to the assumptions previously discussed, all CAP water would be used for irrigated agriculture. Based on this assumption, there would be no industrial and municipal users affected by quality degradation of Colorado River water.

Results of Analyses. There would be no penalty costs in 1980, the assumed base year for this analysis. The use of 1980 as a base for the CAP analysis is comparable to the use of 1960 as a base for analyses of other areas.

Again, the purpose of this study was to measure external diseconomies caused by the degradation of Colorado River water only. In the CAP area it was anticipated that the Colorado River would provide no more than 30 percent of all agricultural water. Thus, the effects of the water quality degradations of the blended supply are diminished at least three-fold, based on the assumption that the qualities of all other supplies would remain constant over time as previously discussed. The results of the direct penalty cost analyses are shown in Table 35.

Summary of Lower Basin and Southern California Areas

The results of the analyses of direct penalty costs are summarized in Table 36 and Figure 19. Based upon this analysis, the total direct penalty cost in 1980 due to mineral quality degradation of Colorado River water would be $7.5 million. The projected total for year 2010 would be $16.3 million. It should be noted that more than 75 percent of the total direct penalties in both target years will be incurred by irrigated agricultural users.

Table 35. Summary of Direct Penalty Cost in the Gila Study Area

Type	1980 (In $1,000 Annually)	2010 (In $1,000 Annually)
Agricultural	0	245.7
Industrial	0	---[a]
Municipal	0	---[a]
TOTAL	0	245.7

---

[a] All CAP water is assumed to be used for irrigated agriculture.

Table 36. Summary of Direct Penalty Costs in the Lower Colorado Basin

Type	1980 (In $1,000 Annually)	2010 (In $1,000 Annually)
Irrigated Agriculture	5,713.5	12,741.8
Industry	162.9	512.8
Municipalities	1,622.0	3,018.0
TOTAL	7,498.4	16,272.6

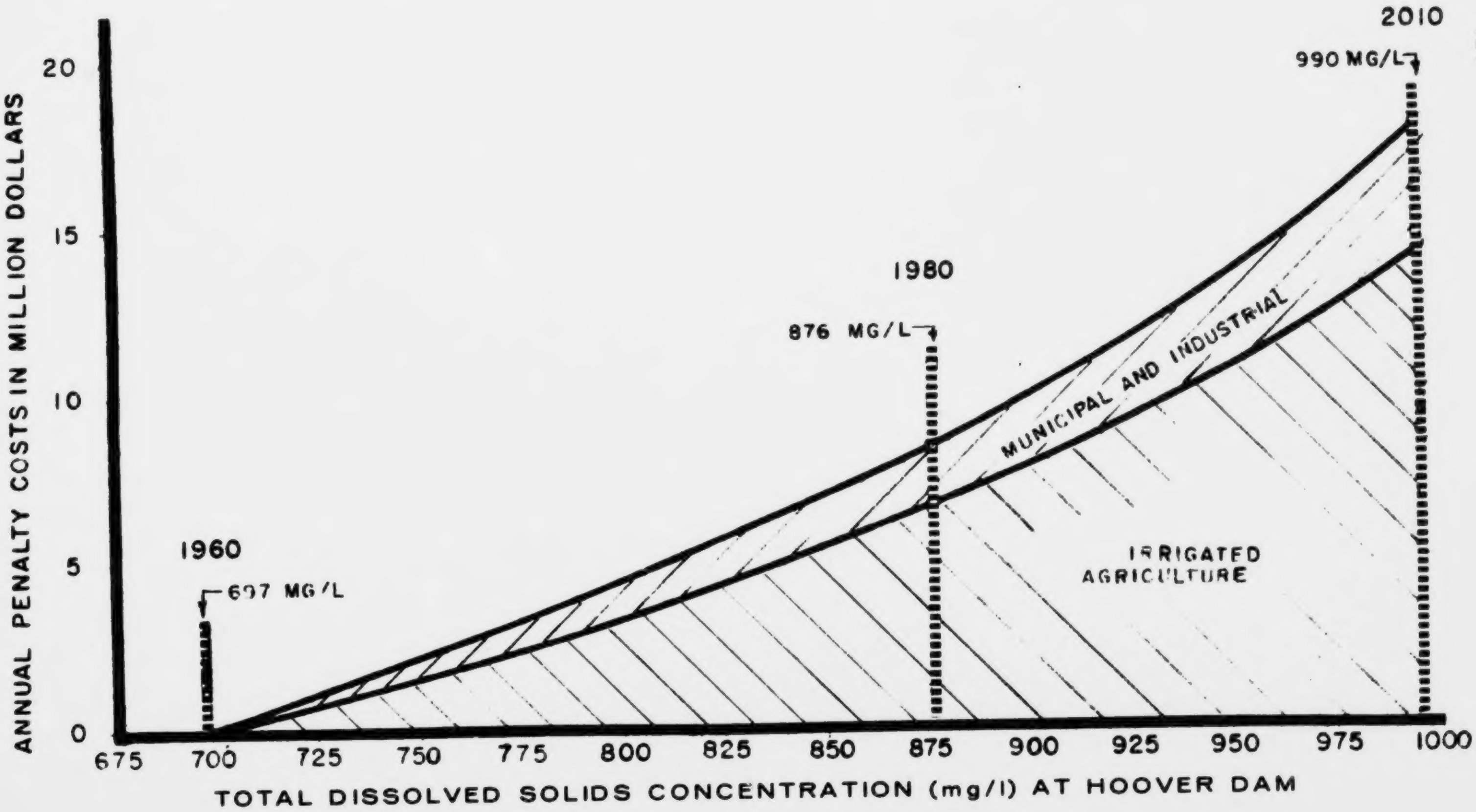


Figure 19. Summary of Direct Penalty Costs Incurred in the Lower Colorado River Basin & Southern California Study Areas

CHAPTER V. REGION-WIDE ECONOMIC IMPACT

INTERDEPENDENCE OF ECONOMIC ACTIVITIES

In addition to the direct economic effects of salinity upon beneficial users of water, there are numerous indirect effects which are brought about by the interdependence of economic activities. These effects are observed in nearly every sphere of economic activity and can be calculated when the dependency of each economic sector upon other sectors is known. Examples of the interdependence between economic activities are discussed in this section.

Water quality degradation of an industrial source causes either a direct loss of production or added costs of treatment and water purchases in order to maintain production. The former situation leads to decreased demands for other resource inputs to the production process forcing the supplier of such input resources to reduce his production. This secondary, or indirect effect, continues in a domino-like sequence until all such interdependent relationships have been exhausted. Added costs of production, the latter situation, induces indirect costs through a misallocation of resources (expenditures for treatment versus expenditures for productive purposes) representing a loss to the optimum regional economic output.

Similar effects are observed in other sectors of the economy. A decrease in the output of agriculture products leads to both direct and indirect decreases in the output of all other industries due to regional economic interdependence. Agriculture decreases its purchases from dependent industries and these industries in turn decrease their purchases from dependent industries until all reduced demands are satisfied. The economy settles back to a new demand-supply relationship.

The purpose of this chapter is to describe the methodology used to calculate the indirect economic effects of water quality degradation.

INPUT-OUTPUT MODEL

The technique and underlying assumptions of input-output analysis are well documented.(45) This chapter is concerned with the application of the model to evaluate mineral quality degradation effects. This type of analysis depends basically on a transaction table. This table is described succinctly by Miernyk[1/] as follows:

> "The transactions table simultaneously describes the demand-supply relationships of an economy in equilibrium. It describes the economy as it is, not as it should be, on the basis of some criterion or set of criteria. The table does not tell us whether the economy is operating at peak efficiency -- it does show the final demand for goods and services and the interindustry transactions required to satisfy that demand."

The input-output table is essentially a record of sales and purchases for each of the sectors defined in the table. The table describes the demand-and-supply relationship of the region's economy for the year designated.

[1/] Miernyk, William H., "The Element of Input-Output Analyses," New York Random House, 1965, Library of Congress No. 65-23339, p. 30. (Reference No. 45)

Construction of the input-output table for a given year is the first of several steps. From the I-O table, a matrix of requirements (direct coefficients) from each industry per dollar of adjusted gross output for each industry is computed, and a corresponding table of interdependence (Direct-Indirect) coefficients is derived. The interdependence coefficients take into account the direct and indirect effects on all industries of changes in final demand for any one industry.

To illustrate the use of this tool, a simplified version of a model composed of the agricultural, mining, and manufacturing sectors will be discussed. Symbolic transactions for this simplified version of the economy are shown in Figure 20. The portion of the transactions table enclosed in black lines is defined as the processing sector.[1] Reading across the top row, A_1, A_2, A_3, and DA represent total sales (TA) by agriculture. Reading down the left column, A_1, M_1, F_1, and PA represent total purchases (TPA) by agriculture. The same procedures apply for mining and manufacturing. The expression in mathematical terms for the agriculture sector

$$TA = A_1 + A_2 + A_3 + DA, \text{ and} \tag{1}$$

$$TPA = A_1 + M_1 + F_1 + PA \tag{2}$$

applied equally with different symbols for the mining and manufacturing sectors. Thus, gross output (TA) minus intermediate use (A_1, A_2, and A_3) equals final use (DA) for the total system.

---

[1] A sector may be defined as a single industry such as mining, or a group of industries such as referred to in the table. The meaning in each case should be clear from the context.

		Industry Purchasing				
		Agriculture	Mining	Manufacturing	Final Demand	Total Gross Output
Industry Selling	Agriculture	A_1	A_2	A_3	DA	TA
	Mining	M_1	M_2	M_3	DM	TM
	Manufacturing	F_1	F_2	F_3	DF	TF
Final Payments		PA	PM	PF	DP	(TP)
Total Gross Outlay		TPA	TPM	TPF	(TD)	

Figure 20. Illustrative Transactions Table

The equation form of the table is more useful for analytical purposes. As described earlier, the direct coefficients show the direct purchases by each sector from every other sector per dollar of output. Thus, for agriculture we can define a direct coefficient as follows:[1]

$$a_{11} = \frac{A_1}{TPA}, \tag{3}$$

$$a_{21} = \frac{M_1}{TPA}, \text{ and} \tag{4}$$

$$a_{31} = \frac{F_1}{TPA}. \tag{5}$$

The production function (equation 2) may be replaced by its equivalent form:

$$TPA = a_{11}\ TPA + a_{21}\ TPA + a_{31}\ TPA + PA, \tag{6}$$

or, since TPA = TA,

$$TA = a_{11}\ TA + a_{21}\ TA + a_{31}\ TA + PA.^{1/} \tag{7}$$

Originally the sales distribution equations were defined as:

$$TA = A_1 + A_2 + A_3 + DA, \tag{8}$$

$$TM = M_1 + M_2 + M_3 + DM, \text{ and} \tag{9}$$

$$TF = F_1 + F_2 + F_3 + DF. \tag{10}$$

If direct coefficients are defined for the mining and manufacturing sectors, these may be rewritten as follows:

$$TA = a_{11}\ TA + a_{12}\ TM + a_{13}\ TF + DA, \tag{11}$$

$$TM = a_{21}\ TA + a_{22}\ TM + a_{23}\ TF + DM, \text{ and} \tag{12}$$

$$TF = a_{31}\ TA + a_{32}\ TM + a_{33}\ TF + DF. \tag{13}$$

---

[1] This simplified description overlooks problems of inventory adjustment, margining and so on which are important to the process but not to illustration of the logic. For a detailed discussion, see Reference No. 46.

These equations in standard form are written:

$$(a_{11} - 1)\ TA + a_{12}\ TM + a_{13}\ TF + DA = 0, \tag{14}$$

$$a_{21}\ TA + (a_{22} - 1)\ TM + a_{23}\ TF + DM = 0, \text{ and} \tag{15}$$

$$a_{31}\ TA + a_{32}\ TM + (a_{33} - 1)\ TF + DF = 0. \tag{16}$$

The same equations in the notation of matrix algebra are written:

$$\begin{bmatrix} a_{11} - 1 & a_{12} & a_{13} \\ a_{21} & a_{22} - 1 & a_{23} \\ a_{31} & a_{32} & a_{33} - 1 \end{bmatrix} \times \begin{bmatrix} TA \\ TM \\ TF \end{bmatrix} + \begin{bmatrix} DA \\ DM \\ DF \end{bmatrix} = 0. \tag{17}$$

In short hand notation the same equations are written:

$$\begin{bmatrix} A - I \end{bmatrix} \begin{bmatrix} T \end{bmatrix} + \begin{bmatrix} D \end{bmatrix} = 0; \tag{18}$$

or solving for the level of total output $\begin{bmatrix} T \end{bmatrix}$,

$$\begin{bmatrix} T \end{bmatrix} = \begin{bmatrix} I - A \end{bmatrix}^{-1} \times \begin{bmatrix} D \end{bmatrix} \tag{19}$$

Equation (19) is the "model" used for evaluating the indirect effects of salinity upon the Colorado River Basin economy. This model may be used to evaluate constraints on output, T; changes in economic structure, A; or changes in demand patterns, D. Although the notation of equation (19) is used throughout this section, it is necessary to emphasize that the effect of changing any individual transaction in the initial table can be evaluated by the model. Thus, equation (19) is merely a short hand notation which indicates the mathematical form of the economic model.

EVALUATION OF TOTAL SALINITY EFFECTS

Because economic activities are interrelated, any change leads the economy to adjust to a new equilibrium condition. Economic changes directly related to water quality degradation were evaluated by using the economic model to determine their influence on the regional economic equilibrium. Total changes in the conditions of economic equilibrium attributable to water quality degradation are defined as the "direct and indirect" effects.

With the analytical model of the economy described in the preceding section, it is possible to evaluate three principal kinds of potential decisions or courses of action: (1) decisions which affect the availability of resources; (2) decisions which affect the demand for goods and services; (3) decisions which affect the production processes. Each of these decisions may deal with either absolute or relative changes, e.g., one can consider limits on the availability of a particular resource, or changes in patterns of resource use through substitution. Furthermore, the decisions are not mutually exclusive. Changes in the production process may implicitly involve changes in: (1) patterns of resource use; (2) demand; (3) resource employment; and (4) production.

The first step in analysis of the direct and indirect economic impact of water quality is to determine what alternative decisions are available to a water user who is confronted with water quality degradation. The direct economic effect of each alternative decision is then identified, and the results are quantified. These steps, taken together, constitute the process of "direct penalty cost assessment" described and evaluated in the preceding chapter. The penalty cost is then injected into the model in order to determine its effect on the regional economy. Different procedures are used to evaluate the effect of each type of potential water quality decision. These procedures are discussed in more detail in the following sections.

Agricultural Penalty Costs

Direct penalty costs incurred by agricultural sectors are interpreted as causing a resource constraint. The cost of developing additional water is the principal factor limiting present and projected future agricultural development. In response to an increment of water quality degradation, an irrigator can increase water use, reduce acreage, or incur a yield loss. As previously indicated, results from the yield decrement method of analysis were chosen as representative of the direct agricultural penalty costs. However, regardless of the penalty cost assessment method used, the effective water supply is diminished by reducing the yield per acre foot. Therefore, the effect of water quality degradation is to constrain agricultural development. In the case of irrigated agriculture it was assumed that any reduction in output would result in fewer consumer and export sales rather than fewer interindustry sales. Consider the definition of the aggregated input-output model presented previously:

$$T = \left[I - A\right]^{-1} D; \qquad (20)$$

if $R = \left[I - A\right]^{-1}$, the equation takes the form

$$T = RD, \qquad (21)$$

or

$$\begin{bmatrix} TA \\ TM \\ TF \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \times \begin{bmatrix} DA \\ DM \\ DF \end{bmatrix}, \qquad (22)$$

or expanding by the rules of vector algebra

$$TA = r_{11}\,DA + r_{12}\,DM + r_{13}\,DF, \qquad (23)$$

$$TM = r_{21}\,DA + r_{22}\,DM + r_{23}\,DF, \text{ and} \qquad (24)$$

$$TF = r_{31}\,DA + r_{32}\,DM + r_{33}\,DF. \qquad (25)$$

In the above equations, r's are referred to as direct and indirect coefficients. These coefficients are fixed by the values of a, the direct coefficients. It is apparent from equations (24) and (25) that if D_1 were to change, because of a constraint on the level of T_1, then T_2 and T_3 would also change. In this simple illustrative case, the magnitude of the change may be easily determined.

From equation (23)

$$\Delta DA = \frac{\Delta TA}{r_{11}} ; \qquad (26)$$

where ΔTA is the direct penalty cost (determined by the yield decrement technique),

ΔDA is the associated reduction in consumer and export sales, and

r_{11} is the direct-indirect coefficient.

The direct and indirect economic impact of water quality costs is defined as the sum of TGO changes in all sectors, corresponding to the final demand change, ΔDA, in the first sector:

$$TEA_1 = \sum_{i=1}^{3} \Delta T_i = \Delta TA + \Delta TM = \Delta TF. \qquad (27)$$

Values of ΔTM and ΔTF can be determined from equations (24) and (25) as follows:

$$\Delta TM = r_{21} \Delta DA = r_{21} \frac{\Delta TA}{r_{11}}, \text{ and} \qquad (28)$$

$$\Delta TF = r_{31} \Delta DA = r_{31} \frac{\Delta TA}{r_{11}}. \qquad (29)$$

Substituting these values into equation (27) gives:

$$TEA_1 = \frac{\Delta TA}{r_{11}} \left(\sum_{i=1}^{3} r_{i1} \right) = \frac{\Delta TA}{r_{11}} (r_{11} + r_{21} + r_{31}), \quad (30)$$

or $$TEA_1 = \Delta TA \ PM_1; \quad (31)$$

where TEA_1 = Total economic effect of costs incurred by the agricultural sector, and

PM_1 = Water quality cost multiplier (Note: that the multiplier is always greater than 1.0, and that it is determined by the structure of the economy).

$PM = 1 + \frac{r_{21}}{r_{11}} + \frac{r_{31}}{r_{11}} + \ldots$; where $r_{ij} > 0$; therefore,

$PM > 1$, and $PM = f(a)$ since $R = \left[I - A \right]^{-1}$.

Industrial Penalty Costs

Direct penalty costs incurred by industries in sectors other than agriculture cause changes in the economic structure. For example, in order to offset the effect of water quality degradation, the industrial water users provide a higher level of treatment for the existing supply or divert, treat, use, and discharge an additional quantity of water. The cost of obtaining or treating the additional water is the direct penalty cost. Such additional costs are identified sector-by-sector and entered in the model.

Water purchased from local governmental entities is assumed to be an expenditure otherwise distributed in the form of income or profit in the final payments sector. Since payments to local governmental entities are also composited in the final payments sector, a payment for additional water is exactly compensating. Since both sector entries are outside the processing sector (refer to Figure 20) there is no interdependence effect and the direct cost of the water purchase is taken as the total cost. This cost is determined by summing the water use cost for each sector:

$$WUC = \sum_{i=1}^{m} WUC_i ; \qquad (32)$$

where m is the number of affected sectors.

Treatment costs of the increment of water required to offset quality degradation is considered to be an increase in the retail sales of water treatment chemicals to the affected industry. To reflect this increase, the corresponding direct coefficient is changed and the model is used to produce a new transaction table. The procedure is illustrated for a simplified model as follows: Assuming a direct effect of "X" dollars, a new direct coefficient is defined.

$$A'_{22} = \frac{A_{22}\, Tm + X}{TM} \qquad (33)$$

$$= A_{22} + \frac{X}{TM}. \qquad (34)$$

This coefficient increases the transaction amount entered in the intersection of row 2 and column 2 of the model by an amount[1] "X".

The second step in calculating indirect costs is to substitute A' into equation (12), and to obtain a new set of solutions[2] for the set of equations (11), (12), and (13). The new set of solutions, as represented by TA', TM', and TF' are:

---

[1] The actual amount of the increase is determined by multiplying the direct effect by a trade margin. For a discussion of trade margins, see Reference No. 46.

[2] The solution given by the model is: $T^* = [I - A^*]^{-1} D$; where A^* is identical to A except for element A_{22} which has been replaced by A'_{22}.

$$TA' = A_{11}\,TA' + A_{12}\,TM' + A_{13}\,TF' + DA, \qquad (35)$$

$$TM' = A_{21}\,TA' + A_{22}\,TM' + A_{23}\,TF' + DM, \text{ and} \qquad (36)$$

$$TF' = A_{31}\,TA' + A_{32}\,TM' + A_{33}\,TF' + DF. \qquad (37)$$

The combined direct-and-indirect effect of water quality due to the increased demand for chemicals per unit of manufacturing sector output is defined as the total increase in gross economic output:

$$TEM_1 = (TA' - TA) + (TM' - TM) + (TF' - TF) \qquad (38)$$

$$= \sum_{i=1}^{n} T'_i - T_i.$$

In the general case, where more than one industrial sector may incur water user penalty costs, the detriments are defined as the total of the detriments incurred by each sector as follows:

$$TEM = \sum_{i=1}^{m} TEM_i; \qquad (39)$$

m = the number of industrial sectors, and TEM_i is the value obtained from equation (38) for each sector.

Two important aspects of this procedure should be pointed out. The first is that direct and indirect penalty costs calculated according to equation (39) are determined for each sector of the model and summed. This procedure is based on the desire to associate the indirect effects of each element of assessed user cost with its source. The step-by-step process also identifies those industries which have a relatively large "secondary" effect (strong interdependence) associated with a moderate direct cost. This so-called "innocent industry" effect is discussed more fully in "An Interindustry Analysis of the Colorado River Basin in 1960 with Projections to 1980 and 2010," University of Colorado, Boulder, Colorado, June, 1968.(46)

The second important aspect is that an increase in gross output is interpreted as a penalty cost. This stems from the fact that more chemical inputs are required to produce at the same level (delivery of goods and services to final demand) in each sector directly affected by water quality. The model measures the increased inputs (costs) required from all other sectors even though the regional level of production remains unchanged. The effects of the increase in resource inputs required to sustain the same level of production is an indication of the regional economic cost of offsetting the impact of water quality.

Municipal Penalty Costs

The effects of increased hardness of water in domestic or municipal uses can be partially evaluated through the cost of softening or demineralizing. In areas where softeners are not used the effects can be measured by the additional outlays for soap and detergents, plumbing repairs, and the like. Thus, the direct municipal penalty costs for degradation of water quality are represented by two effects: increased treatment costs incurred by municipal and private softening plants, and the increased cost of soap and detergents used by individual households. The impact of these direct costs are observed mainly in the trades, services, and government sectors.

Increased treatment costs by municipalities (local government sector) are offset by additional charges or taxes to the consumers, thereby reducing household profits or income. However, since both households and local government are components of the final demand sector (outside the processing sector), the net effect is zero. On the other hand, the purchase of additional chemicals by local government from the trade sector (source of supply for chemicals) and the change in household purchasing patterns in order to purchase additional soap and detergents alter the resulting outputs of the model. The underlying assumption concerning households is that income previously allocated to what might be termed "luxury items" (eating out, incidental services, etc.) will be reallocated to the retail sector to purchase more soap and detergents. To properly handle such factors, a rather detailed procedure is required to adjust the model for the municipal and domestic penalty costs.

The first step in the procedure is to determine the percentage of household purchases allocated to each sector. This is accomplished by dividing the household final demand entry (purchase) in the affected sectors (trades and services) by the total of all household purchases as shown by the equation:

$$h_i = \frac{HH_i}{\sum_{i=1}^{n} HH_i}; \qquad (40)$$

where h_i = the percentage of household expenditures allocated to the $i^{\underline{th}}$ sector,

HH_i = the dollar amount of household purchases from the $i^{\underline{th}}$ sector, and n = the number of all sectors in the economy including processing and final payments sectors.

The next step is to determine the relative reduction in final demand in each of the effected sectors, which are Eating and Drinking, Retail Trade, and Services. These changes are assumed to be proportional to the relative percentage of household expenditures:

$$r_q = \frac{h_q}{h_q+h_r+h_s}, \tag{41}$$

$$r_r = \frac{h_r}{h_q+h_r+h_s}, \text{ and} \tag{42}$$

$$r_s = \frac{h_s}{h_q+h_r+h_s}; \tag{43}$$

where r is the relative reduction in final demand, and Subscripts q, r, and s refer to the eating and drinking, retail trade, and services sectors, respectively.

The next step is to calculate a Final Demand Change Coefficient as follows:

$$d_q = r_q \sum_{i=1}^{m} h_i, \tag{44}$$

$$d_r = r_r \sum_{i=1}^{m} h_i, \text{ and} \tag{45}$$

$$d_s = r_s \sum_{i=1}^{m} h_s; \tag{46}$$

where d is the final demand change coefficient, and m is the number of processing sectors.

The actual change in final demand, corresponding to a direct municipal penalty cost of X is determined as follows:

$$\Delta D_q = -d_q T_q X, \tag{47}$$

$$\Delta D_r = -d_q T_q X + T_q X \tag{48}$$

$$= T_q \ (1 - d_q) \ X, \text{ and}$$

$$\Delta D_s = -d_s T_s X; \tag{49}$$

where ΔD is the change in final demand,

T is the trade margin for the sector indicated, and

d is the final demand change coefficient.

It should be noted that all three final demand changes are entered simultaneously in the model in order to determine total direct and indirect detriments. In this case, total costs are defined as:

$$TMD = \sum_{i=1}^{m} \left| TGO'_i - TGO_i \right| ; \tag{50}$$

where m = the number of sectors in the processing sector,

TGO_i is the output of the $i^{\underline{th}}$ sector before adjustment of final demands,

TGO'_i is the output of the $i^{\underline{th}}$ sector subsequent to adjustment of the final demands, and

the symbol $| \quad |$ means that the absolute value is to be considered; or that all differences are considered to be positive.

TOTAL EFFECT OF WATER QUALITY DEGRADATION

The total effect of water quality degradation is determined by summing the direct and indirect penalty costs for agricultural, industrial and municipal (household) sectors:

TEC = TEA + WVC + TEM + TEH;

where TEC is the total direct and indirect effect of quality deterioration on the subbasin,

TEA is the total direct and indirect economic impact of agricultural detriments,

(WVC + TEM) is the total direct and indirect economic impact of industrial penalty costs, and

TEH is the total direct and indirect economic impact of municipal penalty costs

Again, it is important to note that each of the above measures of cost has been determined by calculating the impact of a direct penalty cost on the economic equilibrium of the unconstrained (with regard to water quality) subbasin economy. The model was used to measure the total effect of water quality degradation. In some cases, as a result of the measurement technique, the shift is in the direction of increasing dollar value of economic output, at a constant level of production while other cases have led to direct decreases in the level of production, therefore, encompassing both income and production effects. If these effects were to be considered simultaneously, changes in dollar value of output would be partially self-cancelling. The result would be a projection of the actual condition of the economy under the influence of a water quality constraint. Such a projection is relevant to the development of a complete economic base study and is considered in the Economics Volume of the Project's Report. It should be noted, however, that one may not arrive at indirect costs by comparing the constrained economic projection with the unconstrained projection. Conversely, one cannot arrive at the constrained projection by comparing direct and indirect penalty costs with the unconstrained economic projection. For these reasons, a sector-by-sector breakdown of the direct and indirect costs has not been presented. Instead, direct and indirect costs are presented by study area total, with a breakdown for the major categories (irrigated agriculture, industrial and municipal) discussed previously (Tables 37, 38, and 39). The results are also shown graphically in Figure 21 for the Lower Main Stem study area, in Figure 22 for the Southern California study area, and in Figure 23 for the Gila study area. Total direct and indirect penalty costs for all three study areas are estimated to be $11.0 million in 1980 and $25.4 million in 2010.

SENSITIVITY OF MODEL TO FLOW INPUT DATA

Sensitivity analysis is a technique used to determine the contribution which each variable makes to the uncertainty of results obtained in a study such as this one. The specific purpose of this section is to determine sensitivity of penalty costs to variations in flow. Mineral quality of the Colorado River at a specific location and time is determined by the quantity of water and salt load carried in the river. As discussed in Chapter III, the analysis of mineral quality was based on the flow period 1942 to 1961, modified to 1960 conditions. However, since various other base periods could have been used, it was deemed advisable to analyze other flow conditions in order to determine whether the results and conclusions would change significantly under these conditions. As an extreme limit, the minimum compact delivery at Lees Ferry was chosen for the sensitivity analysis. This reduced water supply

Table 37. Input-Output Model Results for the Lower Main Stem Study Area

	1980	2010
	($1,000 annually)	
Agricultural Penalty Costs		
Direct	1,096.5	2,423.8
Indirect	765.4	2,237.2
Total	1,861.9	4,661.0
Industrial Penalty Costs		
Direct	106.7	410.2
Indirect	3.8	14.5
Total	110.5	424.7
Municipal Penalty Costs		
Direct	275.0	779.0
Indirect	13.6	39.3
Total	288.6	818.3
Total Direct Penalty Costs	1,478.2	3,613.0
Total Indirect Penalty Costs	782.8	2,291.0
Total Penalty Costs	2,261.0	5,904.0

Table 38. Input-Output Model Results for the Southern California Study Area

	1980	2010
	($1,000 annually)	
Agriculture Penalty Costs		
Direct	4,617.0	10,072.3
Indirect	2,447.0	6,194.5
Total	7,064.0	16,266.8
Industrial Penalty Costs		
Direct	56.2	102.6
Indirect	2.9	5.5
Total	59.1	108.1
Municipal Penalty Costs		
Direct	1,347.0	2,239.0
Indirect	304.8	506.6
Total	1,651.8	2,745.6
Total Direct Penalty Costs	6,020.2	12,413.9
Total Indirect Penalty Costs	2,754.7	6,706.6
Total Penalty Costs	8,774.9	19,120.5

Table 39. Input-Output Model Results for the Gila Study Area

	1980	2010
	($1,000 annually)	
Agricultural Penalty Costs[a]		
Direct	0	245.7
Indirect	0	125.4
Total	0	371.1

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[a] No penalty costs were assessed to municipal or industrial users. For explanation see Chapter II.

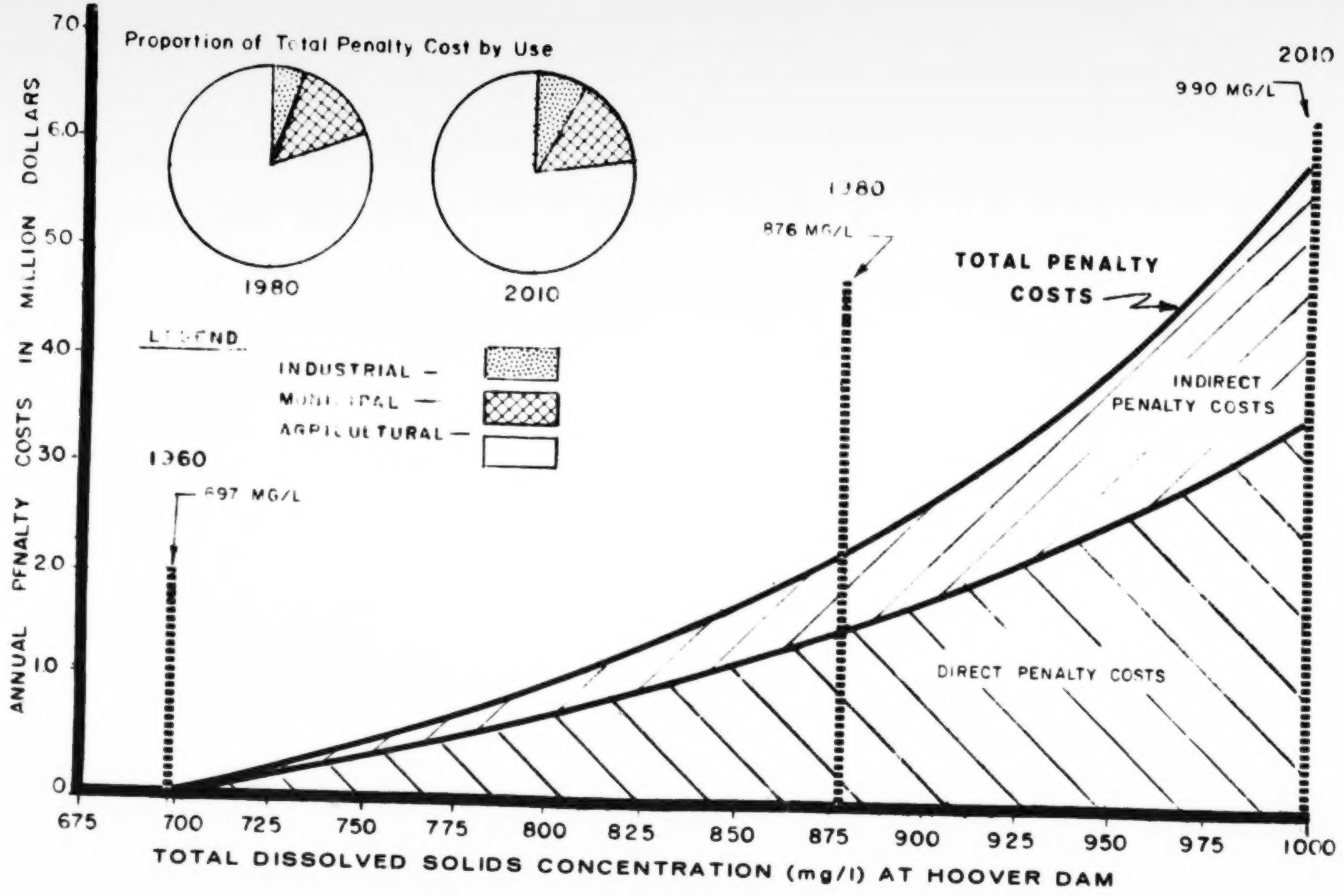

Figure 21. Total Penalty Costs Incurred in the Lower Main Stem Study Area

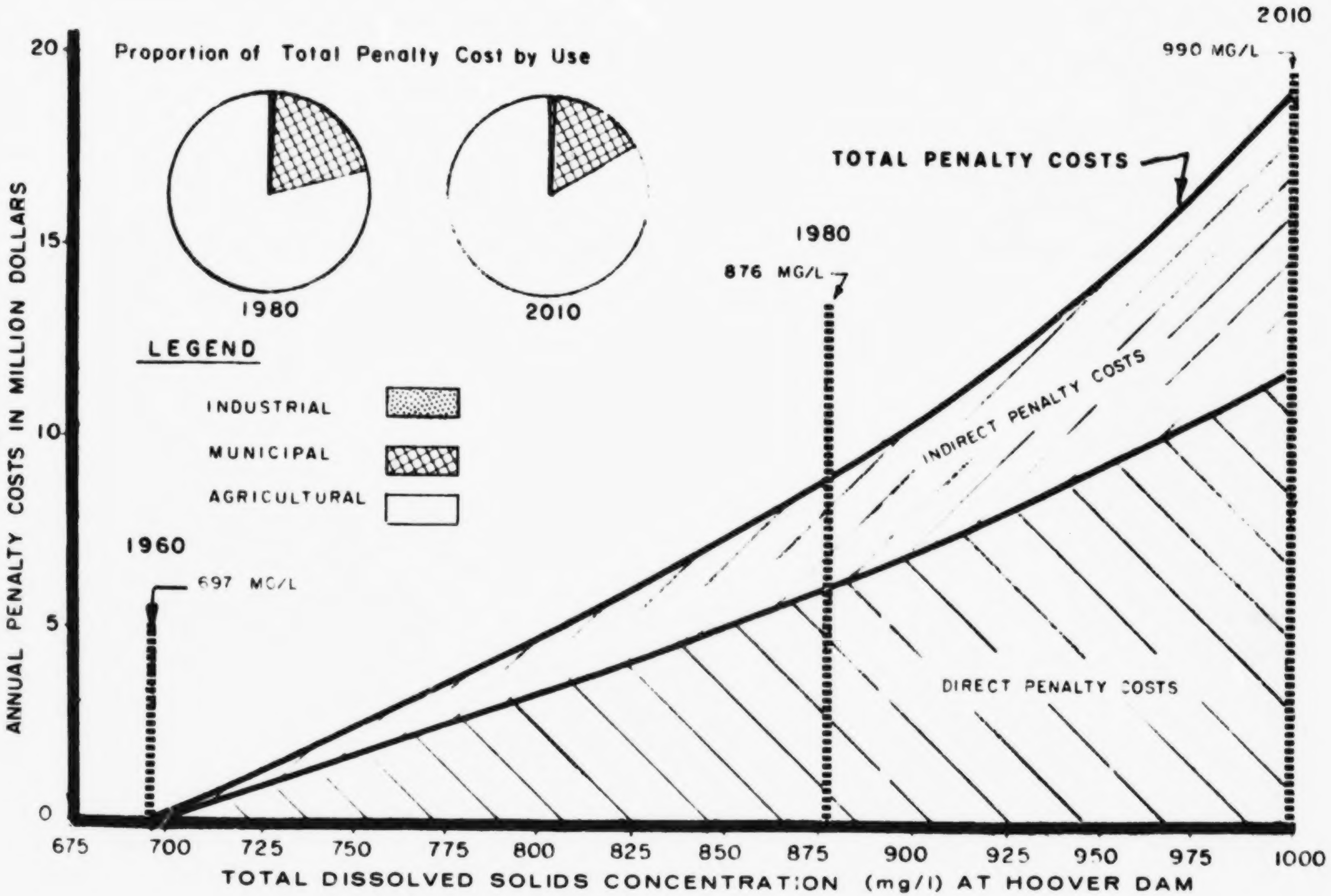

Figure 22. Total Penalty Costs Incurred in the Southern California Study Area

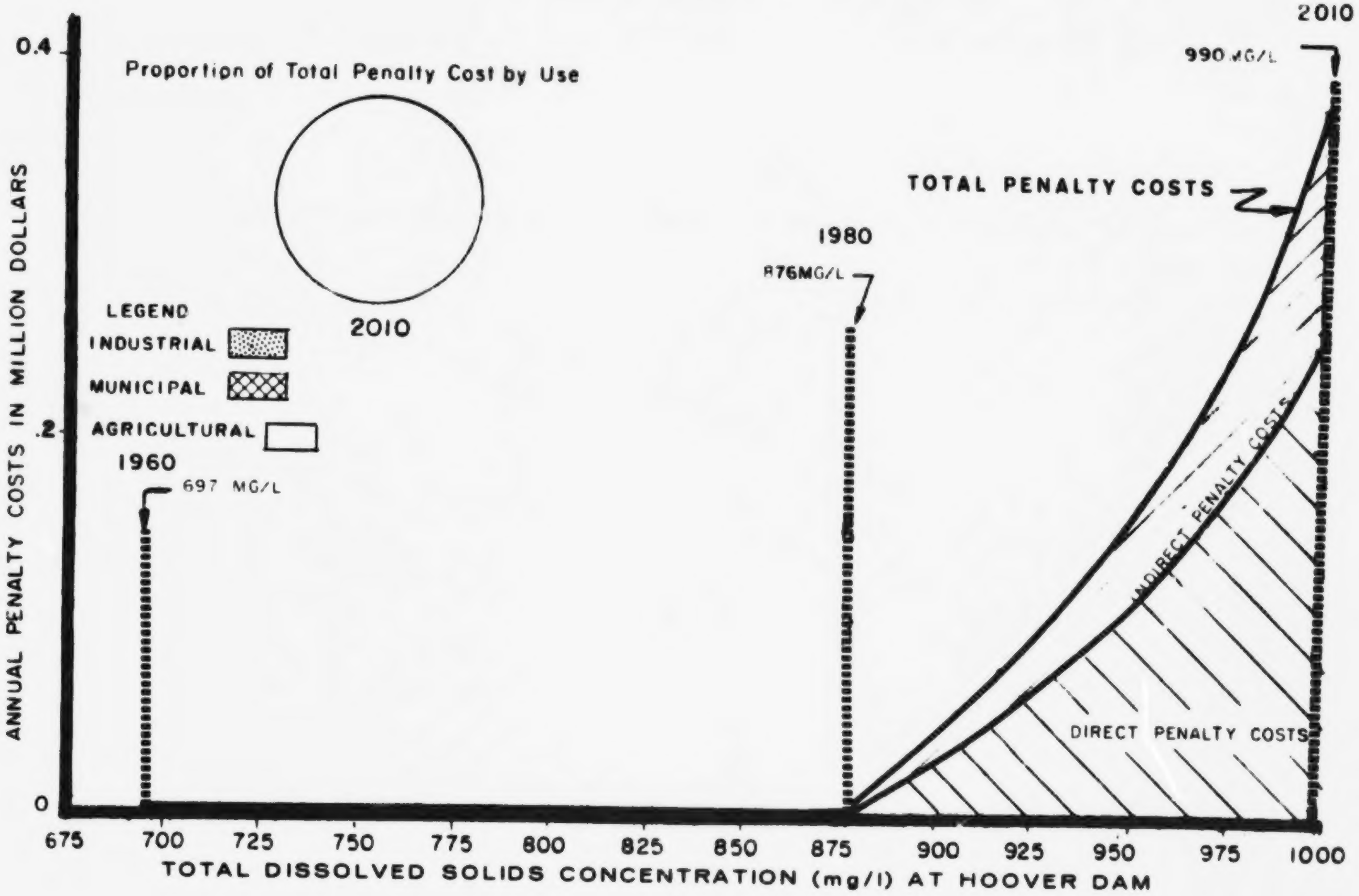

Figure 23. Total Penalty Costs Incurred in the Gila Study Area

was assumed to occur in target year 2010 because the Upper Basin allotment is not projected to be fully utilized until that time

For purposes of this analysis minimum compact delivery was taken as 8.25 MAF per year, based on the assumption that the Upper Basin must deliver 7.5 MAF to the Lower Basin and 0.75 MAF to Mexico. To satisfy Mexico's total apportionment of 1.50 MAF, the Lower Basin must, in turn, deliver 0.75 MAF of their allotted share. A comparison of 2010 water budgets for the Lower Basin for both the projected study condition and the minimum compact delivery condition is shown in Table 40. Allocation of the supply for the Lower Basin under the minimum compact condition is shown in Table 41 This supply condition was incorporated into the flow and salt load routing model, and a new array of mineral qualities was developed as shown in Table 42.

The new array of mineral qualities was incorporated into the model and new total penalty costs were determined The results show that the model is relatively sensitive to flow. Total penalty costs to all users of Colorado River water below Hoover Dam as shown in Table 43 increased from $25.4 million to $27.8 million annually, or about ten percent, because of an assumed reduction in the available water supply of four percent. A comparison of the results based upon the two different flow conditions is shown in Figure 24.

SURFACE EQUATION OF DIRECT ECONOMIC IMPACTS

Figure 25, a display of three traces on a three-dimensional figure called a response surface, illustrates total direct user costs as a function of water quality at Hoover Dam The curves represent total user costs associated with each of the three target years, 1960, 1980

Table 40. Lower Basin Water Budgets for Year 2010 Under Projected and Minimum Compact Conditions

	Projected Supply Condition (maf)	Minimum Compact Supply Condition (maf)
Delivery at Lees Ferry, Arizona	8.629	8.250
Inflows and Water Salvage	1.323	1.323
Reservoir Evaporation & Other Depletions	-1.250	-1.250
Available for Use in Lower Basin	8.702	8.323

Table 41 Assumed Allocation of Colorado River Water Among Lower Basin States & Mexico Under Minimum Compact Conditions

State or Republic	Allocation (maf)
California	4.400
Arizona	2.023[a]
Nevada	0.300
Mexico	1.600[b]
Total	8.323

---

[a] A volume constraint was applied to the Central Arizona Project decreasing the diversion volume from 900,000 acre-feet/year to 373,000 acre-feet/year.

[b] Includes 0.100 maf of uncontrolled and unmeasurable underflows.

Table 42 Mineral Quality for Year 2010 Under Projected and Minimum Compact Conditions

Station	Projected Conditions		Minimum Compact Delivery	
	TDS (mg/l)	Hardness (mg/l)	TDS (mg/l)	Hardness (mg/l)
Colorado River at Hoover Dam	990	460	1,022	470
Colorado River at Parker Dam	985	460	1,018	470
Colorado River at Palo Verde	1,082	495	1,115	505
Colorado River at Imperial Dam	1,223	540	1,256	550

Table 43. Total Penalty Costs for Projected Conditions and Minimum Compact Conditions for Year 2010
($1,000 annually)

Type of Penalty Costs	Lower Main Stem Study Area		Southern California Study Area		Gila Study Area		Total	
	Projected	Min.a/ Compact	Projected	Min.a/ Compact	Projected	Min.b/ Compact	Projected	Min. Compact
Agricultural								
Direct	2,423.0	2,672.3	10,072.1	10,934.0	245.7	82.3	12,740.8	13,688.6
Indirect	2,237.2	2,292.8	6,194.5	7,271.1	125.4	42.2	8,557.1	9,606.1
Total	4,660.2	4,965.1	16,266.6	18,205.1	371.1	124.5	21,297.9	23,294.7
Industrial								
Direct	410.2	469.3	102.6	115.0			512.8	584.3
Indirect	14.5	44.5	5.5	9.2			20.0	53.7
Total	424.7	513.8	108.1	124.2			532.8	638.0
Municipal								
Direct	779.0	841.0	2,239.0	2,416.0			3,018.0	3,257.0
Indirect	39.3	42.0	506.7	535.6			546.0	577.6
Total	818.3	883.0	2,745.7	2,951.6			3,564.0	3,834.6
Total Direct	3,612.2	3,982.6	12,413.7	13,465.0	245.7	82.3	16,271.6	17,529.9
Total Indirect	2,291.0	2,379.3	6,706.7	7,815.9	125.4	42.2	9,123.1	10,237.4
TOTAL	5,903.2	6,361.9	19,120.4	21,280.9	371.1	124.5	25,394.7	27,767.3

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a/ Quantity Unconstrained.
b/ Quantity Constrained.

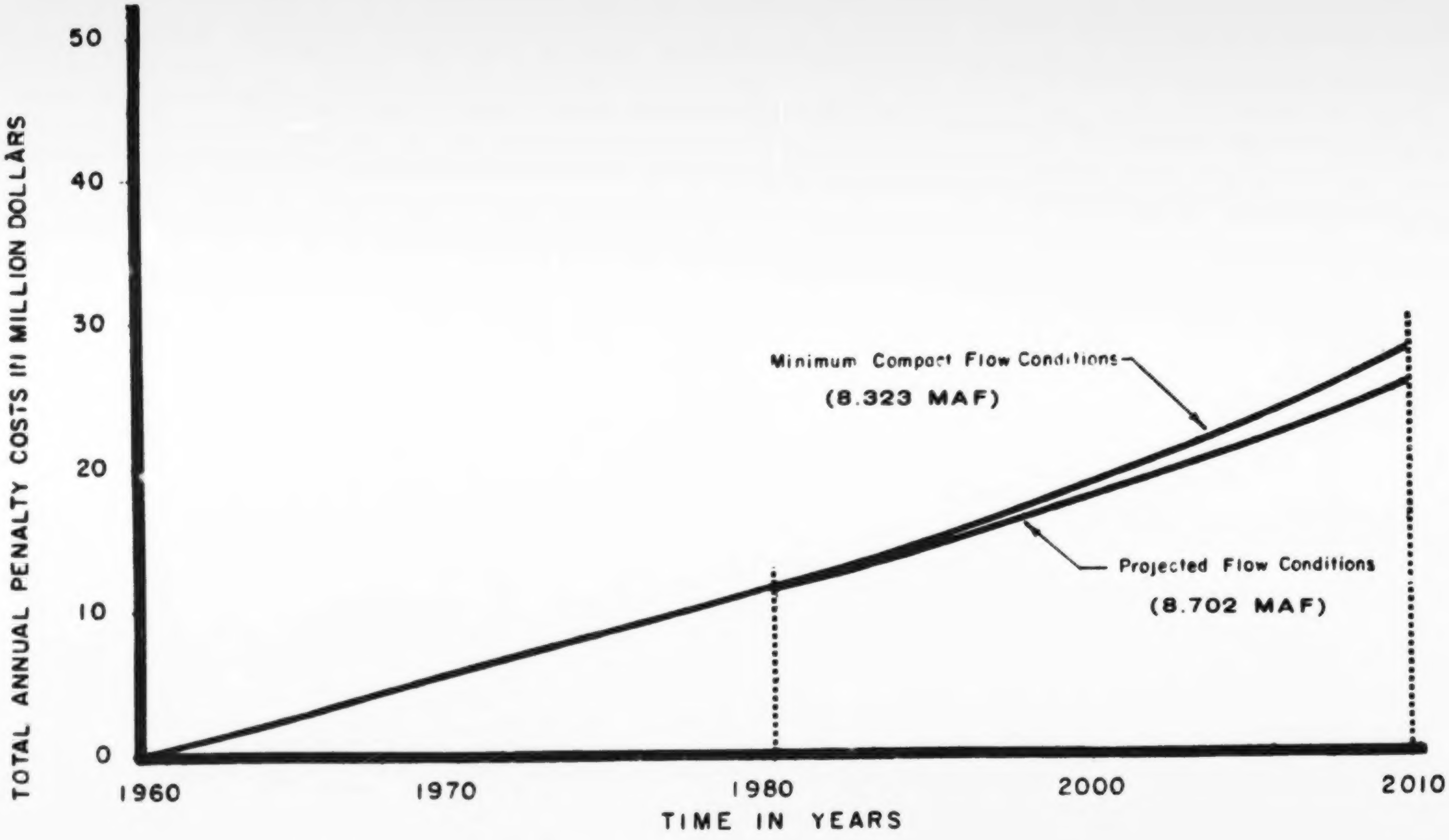

Figure 24. Comparision of Total Penalty Costs for Projected & Minimum Compact Water Supply Conditions

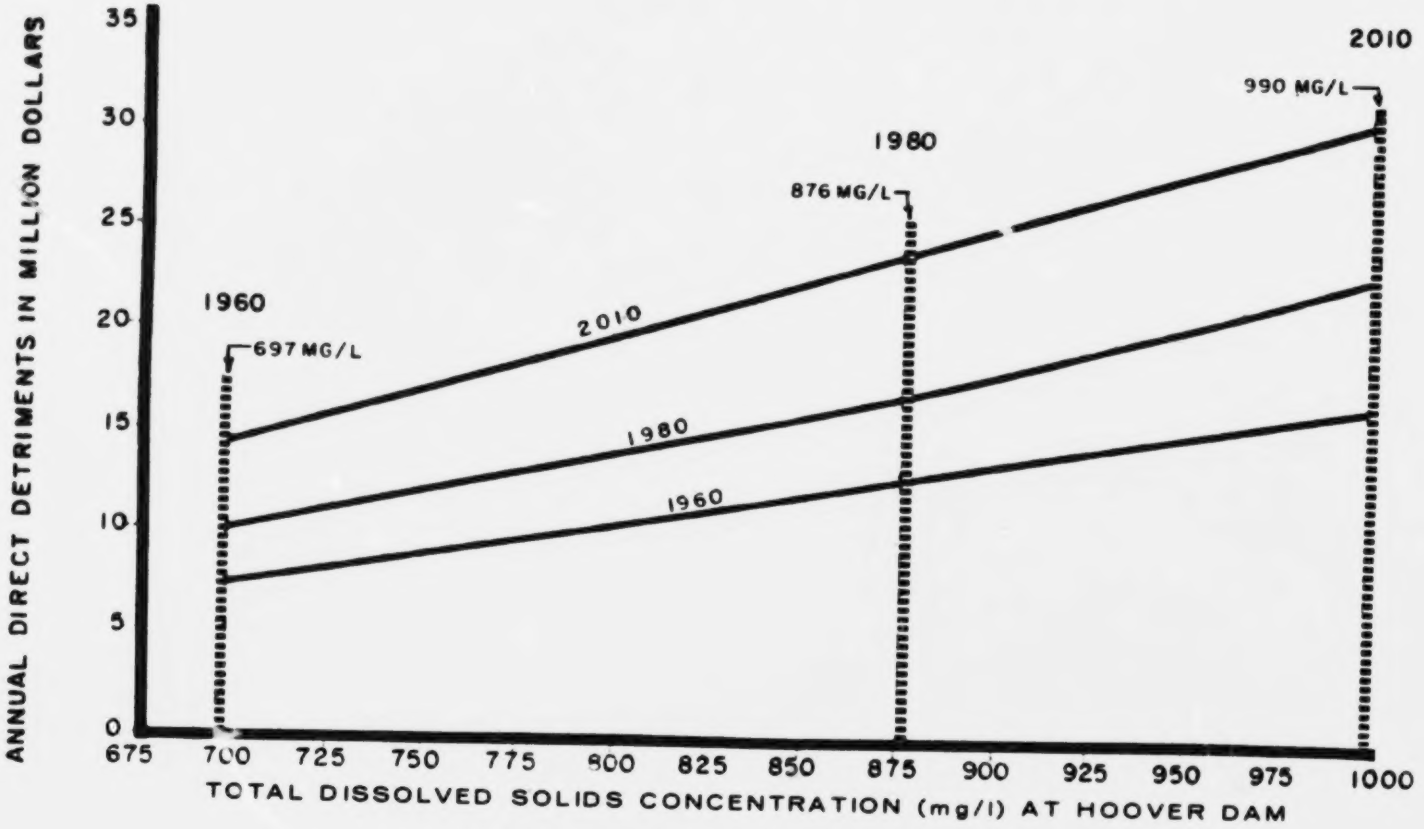

Figure 25. Summary of Direct Salinity Detriments to All Colorado River Water Users Below Hoover Dam

and 2010 The three traces on this surface were selected arbitrarily for illustration purposes. To be more general, an equation was developed that defined the response surface. With the equation, user costs for water qualities and economies at any time in the future can be investigated without duplicating all the detailed analysis described in Chapters III and IV.

The response surface equation is a polynomial in the form:

$$S = Ax^2 + Bxy + Cy^2 + Dx + Ey$$

where S = Annual direct detriments in million dollars below Hoover Dam (1960 dollars);

x = The total dissolved solids concentration (mg/l) at Hoover Dam;

y = The economic year, where 1950 = 0, 1980 = 20, and 2010 = 50; and

A, B, C, D, and E are the coefficients of the polynomial as determined by the least squares technique.

The coefficients are:

$A = 0.22663 \times 10^{-4}$

$BB = 0.45845 \times 10^{-3}$

$C = -0.19157 \times 10^{-3}$

$D = -0.50383 \times 10^{-2}$

$E = -0.17265 \times 10^{0}$

The response surface equation can be used to evaluate the economic benefits which would be realized if the mineral quality at Hoover Dam could be improved. Assuming that means are available to reduce the projected 1975 mineral quality at Hoover Dam from 840 mg/l to 740 mg/l, benefits could be calculated as follows:

For the Projected conditions; $x = 840$, $y = 15$. Thus,

$$S = .22663 \times 10^{-4}(840)^2 + .45845 \times 10^{-3}(840)\ (15) + (-.19157 \times 10^{-3})\ (15)^2 + (-.50803 \times 10^{-2})\ (840) + (-.17265)\ (15)$$

$S = 14.8$ million dollars annually.

For the proposed condition, $x = 740$ and $y = 15$.

Thus

$$S = .22663 \times 10^{-4}(740)^2 + .45845 \times 10^{-3}(740)\ (15) + (-.19157 \times 10^{-3})\ (15)^2 + (-.50803 \times 10^{-2})\ (740) + (-.17265)\ (15)$$

$S = 11.1$ million dollars annually.

The net worth or negative penalty cost to the economies is then,

Worth = 14.8 - 11.1 = 3.7 or \$3,700,000 annually.

The indirect benefits which would accrue to water users would be calculated by input-output analysis.

CHAPTER VI. CONCLUSIONS

Projected degradation of mineral quality in the Colorado River during the next four decades will impose significant economic penalties upon water users in the Lower Basin and Southern California areas. These penalty costs will be incurred generally by consumptive users of water. Little or no detrimental effects are anticipated for non-consumptive uses of water such as recreation, water sports, native fauna, navigation, hydropower generation, and esthetic enjoyment.

Adverse effects of salinity are anticipated in municipal, industrial, and irrigated agriculture water uses. Among these three, irrigated agriculture is by far the most important in terms of amount of water used. Even after considering the heavy urban demand of the Los Angeles - San Diego metropolitan areas, irrigation still accounts for 85 to 90 percent of all water presently consumed in the Colorado River system.

Based upon projected patterns of future water resource and economic development, mineral quality was forecasted at key locations in the Basin for the target years 1980 and 2010. The mineral qualities at Hoover Dam and Imperial Dam are projected as 876 mg/l and 1,056 mg/l, respectively in 1980 and 990 mg/l and 1,223 mg/l, respectively in 2010. These quality levels represent increases in salinity concentrations over 1960 levels of 179 mg/l (25.7 percent) and 297 mg/l (39.1 percent) at Hoover Dam and Imperial Dam, respectively, for the year 1980. These concentrations are projected to undergo additional increases by the year 2010 of 114 mg/l (13.0 percent) and 167 mg/l (15.8 percent) at the same locations, respectively.

Nearly all economic penalty costs will be incurred by water users in the Lower Colorado River Basin and Southern California Water Service area. Direct economic losses to water users in these areas will amount to 7.5 million dollars annually by the year 1980. The magnitude of these damages which represent the direct added costs of using a degraded water supply, will increase to 16.3 million dollars annually by the year 2010.

Indirect economic effects caused by the direct impact upon water users will represent an additional loss to the regional economy of 9.1 million dollars annually by the year 2010. Of the total (direct and indirect) annual economic impact in 2010 (25.4 million) nearly 84 percent will be incurred as a result of the direct impact upon irrigated agriculture water users.

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THE MINERAL QUALITY PROBLEM
IN THE COLORADO RIVER BASIN

APPENDIX C

SALINITY CONTROL AND MANAGEMENT ASPECTS

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGIONS VIII AND IX

1971

THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency was established by Reorganization Plan No. 3 of 1970 and became operative on December 2, 1970. The EPA consolidates in one agency Federal control programs involving air and water pollution, solid waste management, pesticides, radiation and noise. This report was prepared over a period of eight years by water program components of EPA and their predecessor agencies--the Federal Water Quality Administration, U.S. Department of Interior, April 1970 to December 1970; the Federal Water Pollution Control Administration, U.S. Department of Interior, October 1965 to April 1970; the Division of Water Supply and Pollution Control, U.S. Public Health Service, prior to October 1965. Throughout the report one or more of these agencies will be mentioned and should be considered as part of a single agency--in evolution.

PREFACE

The Colorado River Basin Water Quality Control Project was established as a result of recommendations made at the first session of a joint Federal-State "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries", held in January of 1960 under the authority of Section 8 of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.). This conference was called at the request of the States of Arizona, California, Colorado, Nevada, New Mexico, and Utah to consider all types of water pollution in the Colorado River Basin. The Project serves as the technical arm of the conference and provides the conferees with detailed information on water uses, the nature and extent of pollution problems and their effects on water users, and recommended measures for control of pollution in the Colorado River Basin.

The Project has carried out extensive field investigations along with detailed engineering and economic studies to accomplish the following objectives:

(1) Determine the location, magnitude, and causes of interstate pollution of the Colorado River and its tributaries.

(2) Determine and evaluate the nature and magnitude of the damages to water users caused by various types of pollution.

(3) Develop, evaluate, and recommend measures and programs for controlling or minimizing interstate water pollution problems.

In 1963, based upon recommendations of the conferees, the Project began detailed studies of the mineral quality problem in the Colorado River Basin. Mineral quality, commonly known as salinity, is a complex Basin-wide problem that is becoming increasingly important to users of Colorado River water. Due to the nature, extent, and impact of the salinity problem, the Project extended certain of its activities over the entire Colorado River Basin and the Southern California water service area.

The more significant findings and data from the Project's salinity studies and related pertinent information are summarized in the report entitled, "The Mineral Quality Problem in the Colorado River Basin". Detailed information pertaining to the methodology and findings of the Project's salinity studies are presented in three appendices to that report - Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality", Appendix B, "Physical and Economic Impacts", and Appendix C, "Salinity Control and Management Aspects".

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CHAPTER I INTRODUCTION

Salinity is one of the most serious water quality problems in the Colorado River Basin. Like many streams in the arid West, the Colorado River displays a progressive increase in salinity (total dissolved solids)[1/] between its headwaters and its mouth. Salinity concentrations in the Lower Colorado River below Lees Ferry, Arizona are approaching critical levels for municipal, industrial, and agricultural water use. In the face of this present situation, planned and proposed water resource developments, primarily in the Upper Basin, will cause further increases in salinity concentrations in the Lower Colorado River.

As a part of its investigations of interstate pollution problems, the Colorado River Basin Water Quality Control Project (Project) has carried out activities since 1963 directed toward three primary objectives related to the salinity problem. These objectives are:

(1) To assess the nature and magnitude of the salinity buildup in the main stem of the Colorado River and its tributaries,

(2) To evaluate the net basinwide economic benefits associated with various degrees of control, and

---

[1/] The terms "salinity" and "total dissolved solids" are used synonymously throughout this Appendix.

(3) To investigate and evaluate feasible methods of controlling and minimizing salinity concentrations and loads in the river.

Project activities concerned with the first objective are discussed in detail in Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality." To provide the basis for evaluating the economic benefits of salinity control, the second objective, detailed studies of the physical and economic effects of salinity on water use in the Colorado River Basin were carried out. The results of these studies are discussed in Appendix B, "Physical and Economic Impacts." This appendix summarized the present status of knowledge with respect to the second and third objectives. Results of activities completed to date are sufficient to achieve these objectives only provisionally. Most of the evaluations presented herein are based on preliminary data not on final results. Activities are continuing which will improve the store of salinity control knowledge and which will result in refinement and improvement of the information presented. This report can thus be considered an interim summary of the "state-of-the-art" with respect to salinity control and Management for the Colorado River Basin.

Closely related to the salinity control studies described herein were the efforts to establish water quality standards for the interstate waters of the Colorado River system as required by the Water Quality Act of 1965. Early in the process of establishing standards, it became apparent that available information on the technical aspects of management and control of salinity was not adequate to develop equitable, workable and enforceable salinity standards. The water quality standards subsequently developed by the states and approved by the Secretary of the Interior did not include numerical salinity standards. However, the Secretary stated that it would be the intention of the Department of the Interior and basin states to pursue active programs to lay the foundation for setting numerical criteria with emphasis on the demonstration of salinity control measures and ways to revise the legal and institutional constraints that could impede implementation and enforcement. The Project's activities thus form a major link in Department of the Interior's efforts to provide the basis for establishing suitable salinity standards. Activities related to salinity standards are summarized in Chapter II.

A wide range of technical possibilities for salinity control were identified and their potential feasibility for application in the Colorado River Basin evaluated. Present knowledge of many of these control measures is quite limited before actual project application can be anticipated. Present information is considered adequate, however, to provide a basis for preliminary estimates of the potential for salinity control in the Colorado River Basin. The various salinity control measures evaluated are discussed in Chapter III.

A number of technical investigations as well as research and demonstration projects directed towards improving salinity control and management knowledge have been undertaken by other institutions and agencies with financial support from the Federal Water Quality Administration. These activities have contributed to the third primary study objective. The present status of these activities is discussed in Chapter IV.

To provide the basis for determining the potential feasibility of basinwide salinity control, a total of eight alternative control programs were formulated. Cost estimates were prepared for these programs which included three salt load reduction programs, four flow augmentation programs and a water supply treatment program, and the relative costs and water quality effects were compared. The phased implementation of a salt load reduction program was selected as the least cost alternative and costs of the program were utilized to evaluate the economic feasibility of various levels of salinity control.

A number of alternative economic or water quality objectives were identified which a basinwide control program could seek to achieve. The water quality and economic effects associated with each of these objectives for the least cost program were evaluated. The distribution of salinity costs associated with these objectives were evaluated and are discussed in Chapter V.

The Project's investigations comprise essentially a reconnaissance level analysis of the overall salinity problem and provide a preliminary assessment of the potential for achieving a measurable degree of salinity management. It is clear, however, that further investigation and demonstration of salinity control technology will be required before a basin-wide salinity control plan can be formulated and implemented. Also, a number of legal and institutional factors must be analyzed and modified where practical before implementation of a basinwide plan can be assured.

CHAPTER II. MINERAL QUALITY STANDARDS

The salinity problem in the Colorado River Basin (see figure 1) was brought into sharp focus by the passage of the Water Quality Act of 1965.(1) Under this Act, the states were required to adopt water quality standards for their interstate waters along with a plan for implementing and enforcing standards by June 30, 1967. Early in the standards-setting process, representatives of the water pollution control agencies for the seven Basin States recognized that it would be highly desirable to have agreement on certain principles and factors to be used in formulating consistent State water quality standards for the interstate waters of the Colorado River system. A Technical Water Quality Standards Committee was therefore formed for this purpose. It consisted of one representative from the water pollution control agency for each of the seven Basin States. Between August 1966 and December 1967, the Committee held a number of meetings for the purpose of reaching agreement on the principles and factors to be used in developing consistent State water quality standards for the interstate waters of the Colorado River system. At the outset, members of the Technical Committee recognized that, because of legal and institutional constraints combined with lack of technical knowledge on its control and management, salinity would be a most difficult problem to resolve in their standards-setting process.

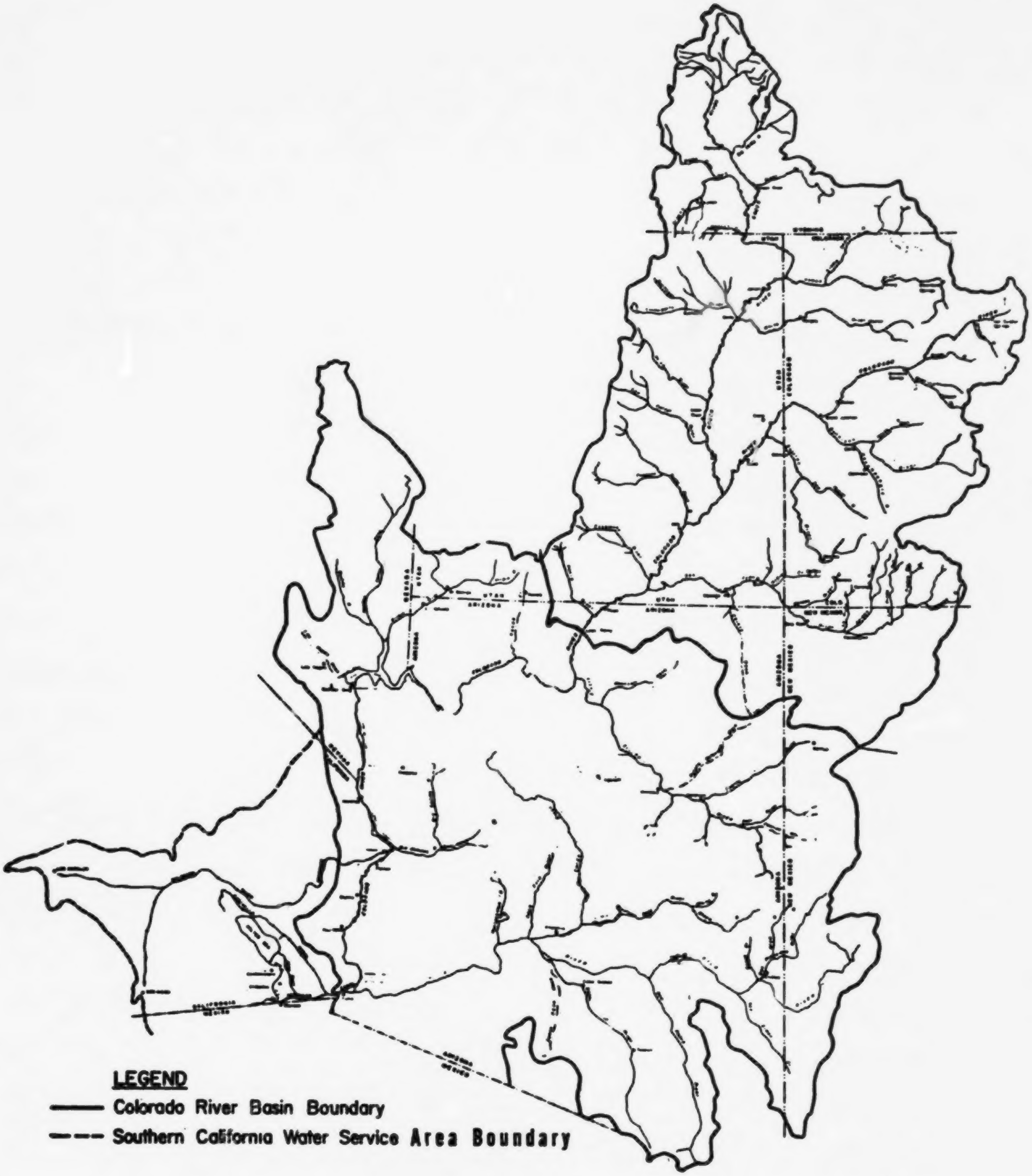
LEGEND
Colorado River Basin Boundary
Southern California Water Service Area Boundary

Figure 1 Colorado River Basin and Southern California Water Service Area

At the fourth meeting held in Phoenix, Arizona, on January 13, 1967, the Technical Committee reached final agreement on "Guidelines for Formulating Quality Standards for the Interstate Waters of the Colorado River System."(2) A significant point covered under "General Considerations" program for establishing within two years the numerical criteria for such specific chemical constituents as chlorides, sulfates, sodium and boron. Representatives of the water pollution control agencies of the seven Colorado River Basin States met in Denver, Colorado, on November 15, 1967 to consider FWPCA position on numerical criteria for total dissolved solids. By unanimous vote, the representatives of the seven Basin States (Conferees) adopted a "Resolution Relative to Numerical Standards for Salinity of the Colorado River System."(3) It was resolved:

> (1) "That the Conferees do not believe it is appropriate that a standard of 1,000 mg/l or any other definite number for TDS at Imperial Dam be set by the basin states or the Secretary of the Interior at this time.
>
> (2) "That the Conferees urge the completion of water quality reports of the Federal agencies at the earliest practicable date, and that thereafter the basin states and Federal agencies again consider the setting of salinity standards for the Colorado River system.
>
> (3) "That the Conferees hereby urge the FWPCA to consider the approval of the water quality standards of the seven Colorado River Basin states conditioned upon ultimate establishment of acceptable numerical salinity standards after completion and consideration of FWPCA and Bureau of Reclamation reports presently underway."

The Chairman was instructed to transmit copies of the resolution to the Secretary, Department of the Interior; Commissioner, FWPCA; and Director, Southwest Region, FWPCA. It was also agreed that each Conferee would attempt by appropriate means to achieve support of the resolution by the Governor of his State and encourage transmission of the resolution to the Congressional delegation.

The Secretary of Interior expressed his views concerning salinity standards for the Colorado River in his statement of January 30, 1968 to the House Subcommittee on Irrigation and Reclamation(4) (House Document 90-5, Colorado River Basin Project, Part II, pp. 705-706). His remarks on this matter include the following statement:

> "The Colorado River is the only major river of the world that is virtually completely controlled. With the existing system of large storage reservoirs it is possible to plan, for all practical purposes, on complete utilization of the river's runoff with no utilizable water escaping to the sea. This means that the limited water supply in the Colorado River Basin must be used and reused and then used again for a wide variety of purposes. In this complete utilization of runoff, the Colorado Basin is unique.
>
> "The River is unique also with respect to the number and extent of the institutional constraints on the division and use of the Basin's water which include an international treaty, two interstate water compacts, Supreme Court decisions, Indian water rights, State water laws, and Federal law.
>
> "These two aspects, in turn, make the problem of setting numerical mineral quality standards for the Colorado River not only unique but extremely complicated. Before discussing this problem further, I would like to state that salinity standards will not be established until we have sufficient information to assure that such standards will be equitable, workable, and enforceable.
>
> "The principal water uses in the Basin include irrigated agriculture, municipal and industrial water supply, fish and aquatic life, and recreation. Salinity in the Colorado River has no significant effect on instream or nonconsumptive water uses such as hydroelectric power generation and water-oriented recreation. However, ever-increasing levels of salinity do have an adverse impact on the consumptive uses of water for both irrigated agriculture and municipal and industrial water supply.

> "Further development and depletion of water allocated to the Upper Basin States will raise the salinity of water downstream.
>
> "Salinity standards must be so framed that they will not impede the growing economy of the Colorado River Basin and yet not permit unwarranted degradation of water quality. This is the hard dilemma which is the core of the problem of establishing equitable salinity standards.
>
> "A decision not to set salinity standards at this time does not and will not preclude getting started with programs to study and demonstrate the feasibility of controlling and alleviating the Basin's salinity problem."

The Secretary also discussed some promising methods of attaching the salinity problem. He concluded his remarks by stating: "Although the salinity problems of the Colorado River are difficult, I am confident that they can and will be resolved."

In letters dated February 2, 1968, to Governors of several Basin States, the Secretary of Interior also made the following statements concerning salinity standards:

> "After consideration of all the factors involved, I have decided that salinity standards should not be established until such time as we have sufficient information to be reasonably certain that such standards will be equitable, workable, and enforceable. Arriving at this decision at this time does not and will not preclude initiating of programs to study and demonstrate the feasibility of controlling and alleviating the Basin's salinity problem."

In a letter to the Chairman, Technical Water Quality Standards Committee for Colorado River Basin States, dated February 12, 1968, the Assistant Secretary for Water Pollution Control, Department of the Interior, made the following comments regarding the Secretary's position on the establishment of salinity standards for the Colorado River:

> "It is the intention of the Secretary that the Department of the Interior and the states pursue active programs to

> lay the foundation for setting numerical criteria at some future time. These programs should focus on devising and demonstrating salinity control measures and finding ways to revise the legal and institutional constraints that could impede the implementation and enforcement of salinity standards."

The seven Basin States' water quality standards for the interstate waters of the Colorado River system, which contained no specific numerical criteria for salinity, were subsequently approved by the Secretary of Interior. No further formal action has been taken by the States toward adopting mineral quality standards for the Colorado River.

CHAPTER III. TECHNICAL POSSIBILITIES FOR SALINITY CONTROL

Salinity increases result from many diverse factors. However, two basic process -- salt loading and the salt concentrating effects of consumptive water use -- are the primary causes of salinity increases. Two types of salinity control measures -- water-phase and salt-phase methods -- may be employed to control or minimize these processes. Water-phase measures are those employed to reduce salinity concentrations by increasing the volume of water available for dilution of a given salt burden. This can be accomplished by conserving the water supply presently available in the Basin or by increasing the Basin supply through importation or other augmentation measures such as weather modification. Salt-phase measures function to reduce salinity concentrations by reducing the salt load discharged to the river system. Salt load reductions can be achieved in a variety of ways including desalination or impoundment and evaporation of highly mineralized spring flows, modification of irrigation practices and improvement of irrigation facilities to minimize salt pickup by return flows, and the subsurface injection of highly saline industrial wastes.

A number of salinity control measures have been identified which have technical merit and which may be applicable to salinity problems in the Colorado River Basin. These measures are outlined in Table 1.

All of the salinity control measures listed in Table 1

Table 1. Technical Possibilities for Salinity Control

I. Measures for Increasing Water Supply

- A. Water Conservation Measures

    1. Increased Watershed Runoff
    2. Suppression of Evaporation
    3. Phreatophyte Control
    4. Optimized Water Utilization for Irrigation
        a. Reduced Consumptive Use
        b. Improved Irrigation Efficiency
    5. Water Reuse

- B. Water Augmentation Measures

    1. Weather Modification
    2. Water Importation
        a. Fresh Water Sources
        b. Demineralized Sea Water

II. Measures for Reducing Salt Loading

- A. Control of Natural Sources

    1. Natural Discrete Sources
        a. Evaporation of Discharge
        b. Injection into Deep Geological Formations
        c. Desalination
        d. Suppression of Discharge
        e. Reduction of Recharge
    2. Natural Diffuse Sources
        a. Surface Diversions
        b. Reduced Groundwater Recharge
        c. Reduced Sediment Production

- B. Control of Man-Made Sources

    1. Municipal and Industrial Sources
        a. Evaporation
        b. Injection into Deep Geological Formations
        c. Desalination
    2. Irrigation Return Flows
        a. Proper Land Selection
        b. Canal Lining
        c. Improved Irrigation Efficiency
        d. Proper Drainage
        e. Treatment or Disposal of Return Flows

have been given consideration in the search for the most practical means of achieving basinwide salinity management. Technical investigation, research and demonstration project activities completed to date have indicated that some of the methods considered are not economically feasible and other measures may not be practical due to institutional and legal constraints or other factors. The salinity control potential of water conservation measures has not been evaluated quantitatively as present legal and institutional constraints would appear to preclude any practical application of such measures at this time. Such measures are discussed in qualitative terms in this chapter however, as a means of identifying their potential should existing constraints be modified in the future.

Implementation of water augmentation measures to increase the Basin water supply, would also provide significant salinity control benefits. The salinity control potential of several augmentation measures has been evaluated in detail. These measures are discussed qualitatively in this Chapter and quantitatively in Chapter V.

A large number of salt load reduction measures were given consideration; however, only a few are considered to be economically feasible at this time. All of the measures considered are discussed qualitatively in this Chapter as a means of comparison. Those measures which appear to be practical or economically feasible include desalination or impoundment and evaporation of highly mineralized flows from discrete sources including mineral springs, diversion of certain stream sections, and reduction of salt pickup by irrigation return flows by lining canals, improving irrigation efficiency and installation of subsurface drains. These measures are discussed quantitatively in Chapter V.

MEASURES FOR INCREASING WATER SUPPLY

Although highly variable from year to year, the Colorado River Basin receives a relatively fixed total water supply from atomspheric precipitation. Much of this supply is depleted by evapotranspiration and out-of-basin diversions with only a small fraction leaving the Basin as discharge of the Colorado River. Under virgin conditions, evapotranspiration occurred from native vegetation, from natural water courses, and from land and snow surfaces.

Development of the Basin's water resources has increased water losses in several ways. Construction of large reservoirs and canal systems has increased evaporation from water courses. The development of irrigated areas has increased the vegetation present in the Basin and accompanying transpiration losses. Irrigation and reservoir construction have also raised the groundwater table in many areas which has been accompanied by increased growth of native vegetation and increased evaporation from the land surface. The amount of water diverted out of the Basin has also increased over the years. Together, these losses have reduced the water supply remaining to carry mineral salts out of the Basin and have contributed to the increases in average salinity concentrations above those concentrations existing under virgin conditions.

Man's activities have also increased the salt burden carried by the river system. This increased salt burden also contributes to the increases in salinity concentrations above virgin conditions but to a lesser degree than the decrease in water supply.

Much time and effort has been directed toward understanding the natural processes which make up the hydrologic cycle. As a result, a number of techniques have been developed for minimizing evapotranspiration. Along with water reuse, these techniques can be classified as water conservation measures.

Study of the hydrologic cycle has also yielded potential methodology for modifying precipitation. Weather modification and water importation are two activities which can be classified as water augmentation measures. The technical merits of water conservation and augmentation measures from the view point of salinity control are discussed in the following sections.

Water Conservation Measures

Water may be conserved at a number of points as it passes through the various phases of the hydrological cycle. Conservation measures may be applied in the headwaters, in the river and reservoir system, and at the point of consumptive use.

Increases Watershed Runoff. Man has attempted to modify the natural vegetative cover of watersheds in a manner which would reduce the rate of runoff following precipitation. Such modification has produced several effects including reduced flood flows, reduced sediment production, and higher base flows during low-flow periods. This latter effect contributed to the belief that holding precipitation on the watershed increased the watershed yield.

From a salinity control viewpoint, the present practices of watershed management may be detrimental. We now know that holding precipitation on the watershed increases evapotranspiration and decreases watershed yield. Reduced runoff rates also increase the opportunity for precipitation to dissolve salts from the soil and groundwater aquifer and salt pickup rates from the watershed may be increased. Increasing the rate of runoff from a watershed may thus produce lower salinity concentrations, both in the water supply derived from the watershed and at other downstream locations. Large downstream reservoirs are available to regulate this increased runoff for downstream use.

The U. S. Forest Service and various state agencies are experimenting with forest management practices as a means of increasing watershed yields and rates of runoff. Some of the practices under study include forest cutting, logging and slash disposal, conversion of bushland to forest, burning of underbrush, and grazing.

A large portion of Colorado River streamflow originates in mountain forest areas. Increasing the water yield and reducing the salt contribution of forest areas could thus have a major impact on salinity problems. Increasing rates of runoff could produce adverse effects however, such as increased sediment concentrations in streams, reduced low-flow volumes with accompanying warmer water temperatures, and degraded fish and wildlife habitat. Studies, conducted jointly by appropriate State and Federal agencies, are needed to determine if watershed management techniques can be modified to improve the quantity and quality of watershed yields without causing the adverse effects previously described. Investigations of techniques for increasing the rate of runoff from non-forested areas, such as the construction of impervious catchment areas and the treatment of solid surfaces are also needed. No estimates are currently available of the increases in watershed yields or decreases in salinity concentrations that could be achieved by application fo such measures.

Suppression of Evaporation. Water losses by direct evaporation from the surface of reservoirs, lakes, streams, and canals are large. Evaporation losses from large, mainstem reservoirs alone are presently estimated to exceed 1 million acre-feet annually under normal operating conditions. Such losses increase salinity concentrations by reducing the water available for dilution of a given salt burden.

Since evaporation losses are directly related to water surface area, one obvious control method for reservoirs is to maintain the water surface at the minimum area practicable.

However, operating requirements place serious constraints upon maintenance of a minimum area. Reservoirs in the Colorado River Basin are also relatively deep with respect to their surface area and significant reductions in storage produce relatively small reductions in surface area.

A significant amount of research effort has been devoted to development of chemical covers for reservoirs such as monomolecular films. Such films have proven effective in suppressing evaporation but their cost and tendency to be broken up rapidly by wind action or biological activity reduce their practicality.

No practical methods for reducing evaporation from flowing streams have been developed. Evaporation losses from irrigation conveyance systems can be reduced by covering canals and by using pipe distribution systems. The use of pipe systems also reduces seepage losses; and, in some cases, the pickup of salt by return flows is decreased. The feasibility of installing pipe distribution systems is dependent upon a number of factors, and construction cannot be justified on the basis of evaporation reduction alone.

The magnitude of evaporation losses is such that research should be continued to develop economical methods of suppressing evaporation. The salinity control effects of enclosed distribution systems should also receive further study to determine if additional benefits would justify the installation of effective evaporation control devices.

Phreatophyte Control. Phreatophytes are non-beneficial plants with a high rate of consumptive water use. Phreatophytes are found in areas where the groundwater table is near the surface allowing the plants to derive their water supply from groundwater. Common locations are along the banks of streams and reservoirs or on wasteland adjacent to irrigated areas. Based on present surveys of phreatophyte acreages, these losses are estimated to total several hundred thousand acre-feet annually. Such losses contribute significantly to increases in salinity concentrations.

Phreatophytes may be controlled by lowering the water table below the depth of root penetration and by removing or destroying the plants by mechanical or chemical means. In most cases where the water table is now lowered, controls must be continued to prevent regrowth. Revegetation of the cleared areas with beneficial crops or with plants having a lower consumptive water use may be a satisfactory method of long-range control.

Some phreatophytes provide erosion control and shelters for livestock. Other phreatophytes provide wildlife habitat which may complement recreational activity. The feasibility of removing such growths would be dependent upon the practicality of providing suitable substitute vegetation with lesser consumptive water use.

Optimized Water Utilization for Irrigation. Irrigation has been practiced in the Basin since the latter part of the nineteenth century. Irrigation practices in many areas have changed little since the traditional methods developed by the early irrigators. Prior to the construction of storage reservoirs and modern canal systems, irrigation supplies were obtained by direct diversion from flowing streams. Streamflow was high during the spring snowmelt but dwindled to very low levels during late summer. A heavy application of irrigation water was made in the spring with the hope that storage in the soil would offset a deficiency of supply in the latter part of the growing season. Such application methods resulted in poor irrigation efficiencies and excessive water diversions.

With the construction of storage reservoirs to even out the seasonal supply, irrigators were slow to adopt more efficient irrigation practices. In many cases water rights were based on the excessive diversions formerly made. Irrigators were reluctant to reduce water diversions as part of their water rights could be lost. Thus, in many areas, irrigation efficiencies are less than optimal and significant water conservation could be achieved by optimization of water utilization.

Water use for irrigation can be minimized by reducing consumptive use through proper selection of land and crops or by improving irrigation efficiency through proper irrigation management. These conservation measures are discussed in the following sections.

Reduced Consumptive Use. The total water consumptively used by a given irrigated area is dependent upon the consumptive use per acre of growing crops, the total irrigated acreage, and the volume of non-beneficial losses such as evapotranspiration

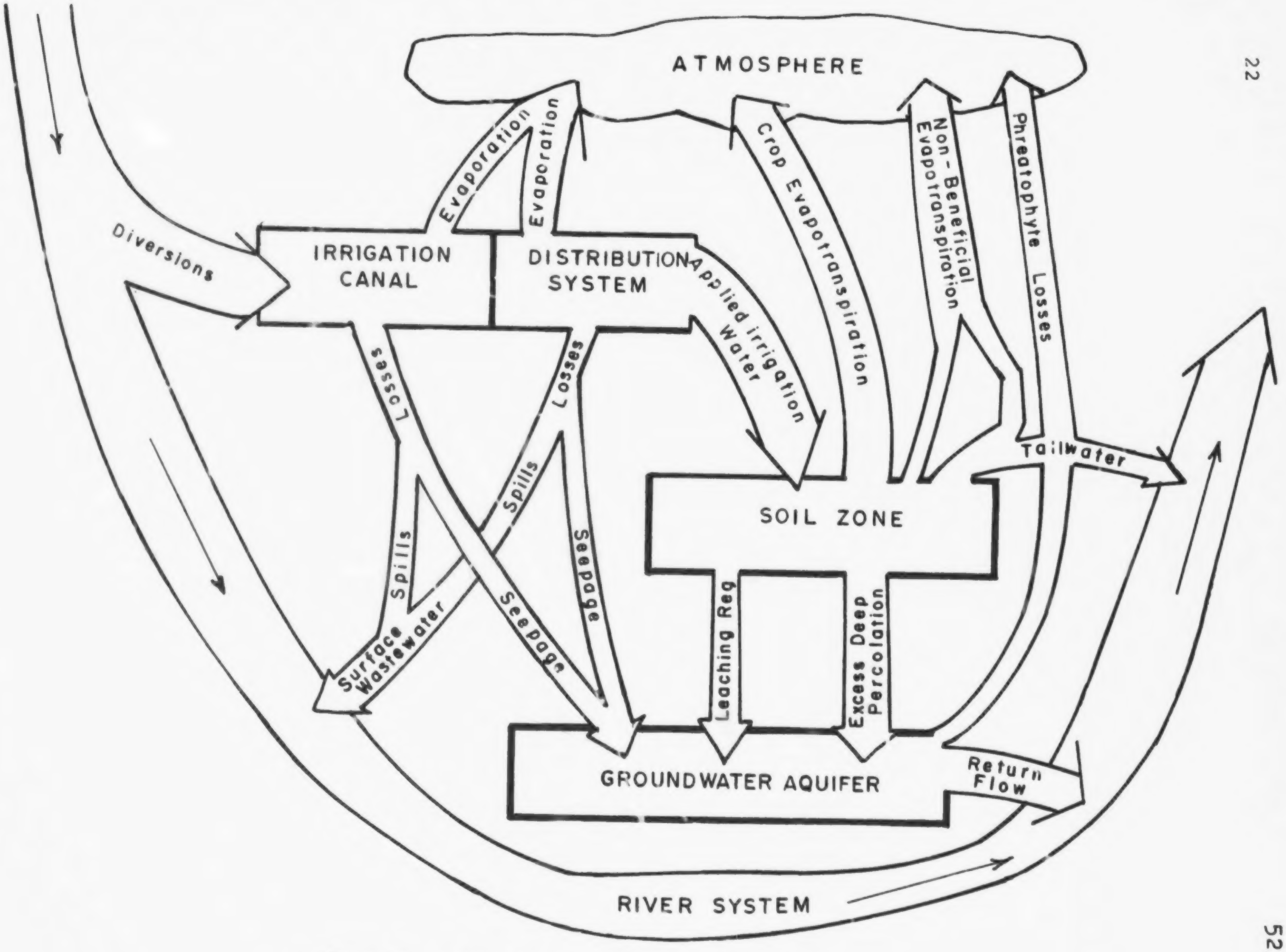
ATMOSPHERE
Evaporation
Evaporation
Crop Evapotranspiration
Non-Beneficial Evapotranspiration
Phreatophyte Losses
Diversions
IRRIGATION CANAL
DISTRIBUTION SYSTEM
Applied irrigation Water
Losses
Losses
Spills
Spills
Seepage
Seepage
Surface Wastewater
Tailwater
SOIL ZONE
Leaching Req
Excess Deep Percolation
GROUNDWATER AQUIFER
Return Flow
RIVER SYSTEM

Figure 2. Schematic Drawing of Irrigation Cycle

by phreatophytes. Reduction of any one of these factors will conserve water.

Different crops have different water requirements. Consumptive use of water could be decreased by growing crops that use less water per unit of food or fiber produced. Thus, water conservation could be effected by promoting the raising of the most efficient water-using crops of equal economic value. The development of new crop varities that are more efficient in water utilization would achieve additional conservation. The water conservation that could be achieved by crop modification would be small however, in relation to the potential conservation that could be achieved by increased irrigation efficiency.

A number of irrigated farms scattered throughout the Basin provide only a marginal economic return to their owners. These farms may be limited to inefficient operation by poor soils, poor drainage, marginal or inadequate water supply, or other factors. Eliminating the irrigation of farms that are not economically efficient would reduce irrigated acreage and consumptive use. Factors that limit the practicality of such action include the difficulty in evaluating which farms should stop irrigating, the problems in transferring water rights and possible relocation of farm owners or tenants.

Significant quantities of water, in the form of surface runoff and excessive return flows, are wasted by inefficient irrigation practices. Some of this waste water may support substantial consumptive use by non-beneficial vegetation located on non-irrigated land. Improvement of irrigation efficiency would reduce the volume of water wasted and would help reduce such non-beneficial losses. Methods of improving irrigation efficiency are discussed in the following section.

Improved Irrigation Efficiency. In normal practice, the volume of water supplied to an irrigated area is much larger than the volume of water consumptively used by growing crops. The ratio of the volume consumed to the volume supplied is known as the irrigation efficiency and may be determined for a number of different points in an irrigation system such as the supply reservoir or the farm headgate. Improving irrigation efficiency reduces the gross supply that must be provided for a given irrigated area and may reduce consumptive use in some cases as previously discussed.

Unnecessary water losses occur at a number of points in the irrigation cycle. These losses are shown schematically in Figure 2. Efficient irrigation requires the application of only enough water to meet the consumptive use requirement of crops plus some excess flow to leach accumulated salts from the root zone (termed the leaching requirement). Efficiency can thus be improved by reducing all other water losses.

Land characteristics such as soil type, soil permeability, land slope, surface drainage patterns, and depth to the water table or impermeable barrier are limiting factors in obtaining high irrigation efficiencies. Thus, proper selection of new land for irrigation can eliminate those areas that would require excessive water supplies for crop production. Classification of existing irrigated areas with respect to land characteristics would allow identification of those areas which possibly should be removed from irrigation because of serious limitations on obtainable irrigation efficiencies.

In many systems, large volumes of water are lost by seepage from canals and distribution systems between the point of diversion from the stream or the storage reservoir and the farm. Reduction of seepage losses by lining canals and pipe distribution systems can substantially increase overall irrigation efficiency.

Perhaps the most significant factor affecting farm irrigation efficiencies is the management of both the timing and method of application of irrigation water. By timing the application to meet crop requirements and by selection of the method of application to match crop and land characteristics, high efficiencies can be obtained. It is estimated that improved irrigation methods and practices could reduce the farm irrigation requirement by as much as 30 percent.

Construction of storage and equalizing reservoirs for irrigated areas obtaining irrigation supplies by direct diversion from uncontrolled streams provide major improvements in farm efficiencies in these areas by allowing a change to a demand system of irrigation. Under such a system, the timing of irrigation applications can be based on crop requirements rather than on the seasonal availability of a water supply. In one irrigated area in Utah, overall irrigation efficiencies increased by an estimated 20 percent following completion of a storage reservoir and inauguration of the demand system of irrigation.(5)

Proper selection of methods of applying irrigation water can also significantly improve farm efficiencies. Flood irrigation methods, which are commonly used in the Upper Basin at present, result in poor irrigation efficiencies in most cases. Use of such methods as border strips, furrows, corrugates, and sprinkler systems can produce field application efficiencies of over 50 percent.

A program to educate and assist irrigators in the selection of methods of application and proper timing of irrigation could significantly increase farm efficiencies. Consolidation of irrigation companies, canal companies, irrigation districts, drainage districts, and private ditch companies or users into one unit for an irrigated area would provide an organization for establishing an educational and assistance program and would also allow more efficient distribution of the available irrigation water. A single entity controlling all of the irrigation and drainage systems in an area could promote more efficient irrigation by establishing rules for determining irrigation needs, economic incentives for installing more efficient irrigating methods or systems and practices and by establishing penalties for misuse of irrigation water. This would require legal and institutional changes, however, and might be difficult to implement in many cases.

Water Reuse

By utilizing the waste water or return flow from an industry, municipality, irrigated area or other water uses to supply the water requirements of additional users, the gross volume of water diverted from a river system to supply all users may be reduced. In the case of a single water user, recycling of all or a part of the waste water can reduce gross water requirements. In the extreme case, wastewater discharge can be eliminated and gross diversions reduced to consumptive use requirements.

The economic feasibility of water reuse is dependent upon the relative costs of sequential water use or of treating wastewater for reuse versus the costs of providing and treating a larger raw water supply. The technical feasibility is dependent upon the availability of treatment methods, such as desalination, capable of producing suitable quality water from wastewater, or the presence of suitable industries, etc., with water quality requirements which will allow sequential water use.

Salinity Control Effects of Water Conservation

Application of water conservation measures should result in a temporary increase in the available water supply of the Basin. However, the long-term effects on supply and the availability of any supply increase for salinity control are not clear.

Reduction of consumptive use by irrigation, by phreatophytes, and in the headwaters area would increase the available water supply. In areas where the present supply is fully utilized, availability of additional water would probably result in new land being placed under irrigation to utilize any surplus water. This action is encouraged by the appropriate water right procedures which prevail in many state water laws. Thus, the long-term effect of such water conservation could be no net change in the water supply available for salinity control.

Reduction of diversion requirements by water reuse or improved irrigation efficiency could have a slightly different effect on available water supply. The immediate result would be an increase in the supply available at the point of diversion. This surplus water would probably be utilized as previously discussed. Increasing the irrigated acreage would increase consumptive use. Thus, the long-term effect of such conservation measures might actually be a decrease in water supply leaving a subbasin. It is doubtful if any increased supply of water available for salinity control would result.

Reduction of reservoir evaporation losses could potentially increase the available water supply for salinity control as such savings would be produced below most Upper Basin use points. Long-term releases from the Upper Basin will probably eventuallly be held to compact allotments. Thus, conserved water would probably be utilized to meet Lower Basin delivery requirements allowing increased consumptive use in the Upper Basin.

The application of conservation measures in areas receiving water exports could potentially increase available supply by decreasing export requirements. However, any increased supply would probably be beneficial used as previously discussed resulting in no increase in the supply available for salinity control.

In summary, under present legal constraints and traditional patterns of water utilization, the application of water conservation measures would produce few benefits as a direct result of increased water supply available for salinity control. Such measures may be significantly beneficial in reducing salt loading as discussed later in this chapter. Also, if legal constraints were modified to make only a portion of the conserved water available for salinity control, significant benefits could result.

Water Augmentation Measures

The actual quantity of water available for use in the Colorado River Basin and its allocation among water users has been the subject of much controversy. It is now apparent that a water shortage will exist in the Basin if the water resource developments proposed by various local, state, and federal agencies are carried to completion. To alleviate this shortage, a number of water augmentation measures have been investigated. These measures include weather modification to increase Basin precipitation and various schemes to import high quality water from other river basins or from the ocean following desalination. A number of potential water augmentation measures are discussed in the following sections.

Weather Modification. Increasing precipitation and watershed yield by weather modification is a relatively new concept. Consequently, operations in this field have not progressed significantly beyond the pilot stage. Pilot scale activities conducted for several years in several states by a number of agencies including the Bureau of Reclamation have shown the technical feasibility of increasing watershed runoff by as much as ten to twenty percent.(6)

Research has been initiated by the Bureau of Reclamation to investigate the feasibility of augmenting Colorado River flow by weather modification. A five-year pilot program of weather modification in the Upper Basin was initiated in September 1968. Seeding of target areas will begin during the 1970-1971 winter season.

Preliminary estimates indicate that an annual watershed yield increase of as much as 1.87 million acre-feet might be obtained by a full-scale, basinwide weather modification program.(6) Costs are estimated to total less than $1.50 per acre-foot of increased yield. Results of the pilot program will allow these estimates to be verified and refined.

A full-scale program would probably concentrate on increasing snowfall in the high mountain areas of the Upper Basin. Since runoff from these areas is generally low in salinity, the increased yield would probably be low in salinity also, with significant salinity control benefits.

Water Importation. Traditionally, man has devised schemes for transporting water from areas of excess supply to areas of need whenever water shortages have developed. Thus, the impending water shortage in the Colorado River Basin has spawned a number of diverse and imaginative proposal for augmenting basin supply by importation of high quality water from various sources outside the basin. At least six major projects which would import water from other basins have been proposed in the past. In most cases these proposals envisage tapping rivers in the Pacific Northwest which, at present, have surplus water available.

In addition, several international water resource development schemes have been proposed which would integrate a number of river systems in Canada and the United States. Surplus Canadian water could be diverted southward by such development to a number of water-short areas including the Colorado River Basin.

Water imported from most of the sources considered by these schemes would be high quality with relatively low salinity concentrations (less than 300 mg/l). The introduction of large quantities of this low salinity water could substantially reduce salinity concentrations at a number of locations in the Basin. The degree and location of resulting salinity control is dependent upon the locations of both the point of importation into the Basin and the point of consumptive use. Significant quantities of salt will be imported along with the water thus increasing the salt burden carried by the river system. If water were imported into the Upper Basin and significant quantities consumptively used at that location, the salt load reaching the Lower Colorado River would be increased and the salinity contol effects of flow augmentation would be less than if the entire volume of imported water were allowed to reach the

Lower Basin. The proposed location and magnitude of water imports and associated consumptive use must be carefully evaluated for each importation scheme to insure that the salinity control effects of water importation are maximized.

Another potential source of high quality water for importation into the basin is demineralized sea water. Desalination techniques have steadily improved in recent years with concurrent reductions in unit costs of demineralized water. At present, desalination is not competitive with alternative sources of fresh water. It is anticipated that unit costs of demineralized water will continue to decrease as a result of continued research and development in this field. Thus, desalination should receive further consideration as a source of imported water.

The Gulf of California and Pacific Ocean are in relatively close proximity to the Lower Colorado River and to areas utilizing large amounts of Colorado River water. Demineralized sea water from these two sources could potentially be utilized to augment the Basin supply directly or to indirectly increase the supply available for use in the Basin by exchange of water outside the Basin. By exchanging demineralized water for Colorado River water now diverted out of the Basin to such areas in Southern California, out-of-basin diversions could be decreased resulting in an increase in the supply available for use in the Lower Colorado River Basin. If the demineralized water were imported into the Basin to a point such as Hoover Dam, significant reductions in salinity concentrations in the Lower Colorado River would result. Decreasing out-of-basin diversions by exchange of water would produce little effect on salinity concentrations in the Lower Colorado River. Significant improvement in the quality of the water supplied to the area receiving the demineralized exchange supply would result however.

A proposed large-scale desalination plant located near Los Angeles has received serious consideration as a source of supplemental water supply for that metropolitan area. Depending upon the timing of the construction of this facility, this source could possibly be utilized to supply water in exchange for present Colorado River diversions.

A reconnaissance study completed by the Bureau of Reclamation in January 1968, determined that it may be technically feasible to import demineralized sea water from a desalination plant, located between Los Angeles and San Diego on the Pacific Ocean, to augment the flow of the Colorado River at Hoover Dam.(7) Staged development with flow augmentation increasing from one-million acre-feet in 1990 to two-million acre-feet in 2010 was evaluated. A large aqueduct and numerous pumping plants would be required to convey the demineralized water to Lake Mead. Thus, the cost of such imported water would be high. This source could also be utilized to provide exchange water to the Southern California area. An exchange scheme would eliminate the need for the lengthy aqueduct with a significant reduction in average water costs. However, no salinity control in the Lower Colorado River would result.

A related study of a potential desalination plant located on the Gulf of California in Mexico has been conducted jointly by the United States and Mexico under the chairmanship of the International Atomic Energy Agency.(80) This study demonstrated that it would be technically feasible to provide a supplemental water supply for the Lower Basin from such a source.

MEASURES FOR REDUCING SALT LOADING

Salt is discharged to the Colorado River system from a variety of sources, both natural and man-made. Man-made sources appear to be most amenable to successful control. Some natural sources, particularly discrete sources, may also be controlled. Control measures may be employed to either remove the salt load from the river system at the point of discharge from the source or to reduce water flow through an area of salt pickup and thus reduce the salt contribution of such an area. Specific control measures which may be applicable in the Basin are discussed in the following sections.

Control of Natural Sources

A number of natural sources of salt existed in the Basin prior to man's arrival. These sources remain relatively unchanged in magnitude by man's activities. The necessary technical knowledge is available to control some natural salt loads. However, the economic feasibility of such control has not been fully evaluated.

Natural Discrete Sources. Discrete sources encompass flow from springs, seeps, and other localized, concentrated discharges. Since such sources contribute high salt loadings from a small area, effective control may be technically feasible. Discrete sources may be controlled by removing the entire discharge from the river system, by removing only the salt load from the system, or by preventing any discharge from the source.

A number of discrete sources discharge to small tributary streams or have well defined discharge channels. In such cases the entire discharge may be intercepted and appropriate control measures applied. The intercepted flow could be conveyed to an impoundment and confined for evaporation, thus effectively removing the entire discharge from the river system. Application of this measure requires adequate area for an evaporation closed basin. Such impoundments may be developed and managed for recreation, wildlife habitat, or other beneficial uses. One drawback to this measure is that evaporation losses in the basin are increased. This should be utilized for moderate to highly mineralized discharges or no net reduction in salinity will occur.

Small sources of highly concentrated brines may be controlled by subsurface disposal. This method is feasible only if suitable geological formations are available to confine the brine and prevent any return flow to the river system.

Demineralization of the collected discharge is an effective means of removing the salt load from the river system with only a small depletion of water discharged by the source. Two factors limit the feasibility of demineralization. The concentrated brines resulting from this process must be disposed of by one of the two methods discussed earlier. The most serious limitation is the lack of a low coast method of demineralization for the small discharges contributed by discrete sources.

In a few cases, mineral springs may be the outlet for an aquifer confined by impermeable boundaries on all sides. It may be technically feasible to plug the aquifer outlet or to apply hydrostatic pressure to suppress aquifer outflow. Such action could completely eliminate the discharge and salt load from such sources. However, a more probable result, following a period of adjustment, would be that the same volume of flow would reappear at some higher elevation near the aquifer recharge area. In this case the discharge would probably have a much lower salinity concentration. Thus, the salt load would be reduced with little or no loss of aquifer yield.

Natural Diffuse Sources. Over half of the salt load discharged to the Upper Basin river system is contributed by surface runoff and ground water inflow from diffuse sources. Surface runoff picks up salts as it passes over the surface of the soil and salt-bearing formations. Additional salt is believed to be picked up from sediments carried in suspension by streams. Ground water picks up salt as it percolates through the soil profile and moves through aquifers. Measures for controlling diffuse sources are thus aimed at reducing the opportunity for surface runoff and groundwater to leach or dissolve minerals from soil and underlying geological formations.

Salinity contributions from natural runoff may be decreased by various measures aimed at reducing the extent and amount of water infiltration in areas of high salt pickup. For example, contour ditches might be constructed to intercept runoff and carry it rapidly into the stream, and surface sealants might be used to control the percolation of surface waters into the soil profile. In local areas where salt is picked up from formations crossed by the stream channel, it may be possible to construct an impervious channel or a bypass channel to prevent contact of water with the saline formation.

Highly mineralized groundwater is discharged by aquifers in some areas. By utilizing diversion or surface sealing techniques to reduce the recharge of the aquifer, displacement of this saline groundwater could be reduced with resulting reductions in salt loads discharged to the system. This approach may also have application to the control of mineral springs.

Percolation of water into the alluvium and shallow ground water underlying river valleys exposes water to the underlying formations much like the percolation of irrigation return flows. Reducing the underground movement of such water should, in most cases, reduce the salt load derived from valley soils and underlying formations.

Sediment swept into the stream from sheet and channel erosion is weathered by continued exposure to well aerated water, and by persistent turbulent mixing. The amount of salt contributed from this source is not known. Numerous erosion control measures have been developed for land protection but little is known about how they affect salinity. Additional study of sediment and salinity relationships will be required to devise effective control techniques.

All of the control measures discussed above involve some form of modification of the movement of surface or groundwater. Flood control, wildlife habitat and water rights are just a few of the various factors that should be carefully evaluated before such modifications are carried out.

Control of Man-Made Sources

Man has increased the salt burden carried by the river system by the discharge of municipal and industrial wastes and by heavy utilization of water for irrigation. Since man has control of such water use, these sources of salt may be more completely controlled than natural sources.

Municipal and Industrial Sources. Municipal wastes are generally relatively low in salinity. With the exception of oil field brines and uranium mill effluents, industrial wastes are also relatively low in salinity. The most effective means of controlling these salt sources are lagooning and evaporation of the wastes, injection into deep formations, or discharge into closed basins. These control measures result in the removal of the entire waste flow from the river system. Due to the low salinity concentrations, the loss of water involved in eliminating such waste discharges would, in most cases, offset decreases in basin salinity levels resulting from removal of salt from these sources. Thus, salinity control measures should be considered for only the most concentrated sources.

Several abandoned oil test wells discharge highly mineralized water. Such flowing wells can frequently be controlled by plugging the casing with concrete. Alternatively, the discharge can be disposed of in the same manner as natural spring flow.

It should be noted that since the salt load from municipal and industrial sources represents a small fraction of the total basin salt burden, complete control of such waste discharges would have little effect on basinwide salinity problems.

Irrigation Return Flows. Irrigation contributes an increased salt load to the river system in a number of different ways. When new land is brought under irrigation, any highly soluble salts present in the soil are leached out by the irrigation water in a relatively short period of time. As irrigation continues, additional salts are dissolved from the soil. These dissolved salts are picked up by any excess irrigation water and returned to the river system as surface wastewater or as groundwater flow. This pickup of salts from the soil by return flows may continue for many years.

The major portion of return flows usually percolates downward into the groundwater aquifer and then moves horizontally either into drains or to the river system. If the groundwater is highly saline, the return flows may displace large volume of the saline groundwater with resultant large salt loads entering the river system. Return flows may also pick up significant salt loads from aquifer materials or underlying formations if sufficient soluble salts are present in these locations.

Wastewater from inefficient practices may flow onto or under adjacent non-irrigated land. Evaporation from such lands concentrates salts drawn to the surface by capillary flow into a surface crust which is easily removed by surface runoff. Irrigation may thus indirectly contribute to salt pickup from non-irrigated lands.

Salt loads contributed by irrigation may be controlled by the proper selection of land to be irrigated, by reducing return flows to a minimum, and by intercepting return flows for treatment or disposal. Specific control measures are discussed in the following sections.

Land Selection. Many soils within the Colorado River Basin contain high concentrations of soluble salt. Irrigation of these soils results in high salt pickup by return flows during the initial leaching period. Large salt loads are also contributed by the irrigation of shallow soils overlying highly saline shales. Classification of all lands in the Basin would allow identification of these problem soil areas. Cessation of irrigation of shallow soils overlying shale would lower the Basin salt burden. It may be possible to purchase the water rights or the land and water rights and discontinue irrigation of some of these shallow soils. Major problems associated with purchase of this type of land would be the disruption of the owner's farm operation and the transfer of water rights to other land or other uses. Some state water laws prohibit separating the water rights from the land or transfer or sale except for higher classified uses. Additional investigations and research are needed to determine the salinity control benefits which may be derived from land selection.

Canal Lining. Seepage losses from unlined irrigation canals are frequently large. These seepage losses contribute to the volume of return flows which pick up salt from groundwater aquifers. Reducing seepage would reduce the salt load of return flows in such cases.

Seepage losses also occur from farm ditches and distribution systems. In some areas canals are kept full during the non-irrigation season to provide livestock water. Providing enclosed or pipe distribution systems would reduce farm seepage losses. A pipeline system for winter livestock water supply would eliminate the need for maintaining flow in the canals year around.

Except for some areas where high value crops are grown, relatively little canal lining or use of pipe distribution systems has been accomplished in the Upper Basin. Thus, a high potential exists for large reductions in return flows as achieved by these types of systems.

Improved Irrigation Efficiency. Low irrigation efficiencies result in excess return flows. Improvement of irrigation efficiencies, as discussed in a preceding section on water conservation, would reduce the volume of return flows and reduce salt loads in the same manner as reducing canal seepage losses.

Drainage. Open surface drains and underground tile drains have been installed in a number of irrigated areas. These drains were usually provided to lower existing high water tables or to prevent water logging by irrigation. To reduce costs, drains were usually constructed as deep and as far apart as soil conditions would allow. Such practices result in long flow paths for return flows.

By installing closely spaced, shallow tile drains, salt loads may possibly be reduced by shortening the flow paths of return flows. Also, shallow drains may reduce the deep displacement of saline groundwater. Surface drains to intercept surface runoff and irrigation tailwater could also reduce the pickup of salt from non-irrigated lands.

Interception of Return Flows. Irrigation return flows reach the river system by a variety of routes. Much of the flow may occur as increased groundwater discharge spread over a wide area. In such cases interception of return flows may be difficult. In some cases, however, return flows may be collected by drains or small tributaries and concentrated into a single stream that may be easily intercepted and conveyed to a treatment or disposal facility.

Once collected, irrigation return flows may be controlled in the same manner as mineral springs discharges. Evaporation, desalination, and subsurface injection into geologically closed formations are technically feasible control measures. The practicality of utilizing these control measures for return flows is limited however, by the same factors as discussed in the section on mineral springs.

CHAPTER IV. STATUS OF SALINITY CONTROL ACTIVITIES

A number of research, demonstration and technical investigation activities related to salinity control have been completed or are underway in the Colorado River Basin. These activities have substantially added to the knowledge of the Basin's salinity problem and have developed improved salinity control technology. In addition, research and technical investigations in other geographical areas have provided technology applicable to the Basin. In spite of this additional information and knowledge, present salinity control technology is still limited and additional research and technical investigations will be required before an effective salinity control program can be implemented. Information developed by these activities is sufficient, however, to provide a basis for preliminary estimates of the potential for salinity control presented in the following chapter. The following sections outline the current status of salinity control activities in the Basin and discuss some of the recent developments and their application to formulation of a salinity control program.

TECHNICAL INVESTIGATIONS

Technical investigations of the salinity problem have been conducted by the Colorado River Basin Water Quality Control Project of FWQA (Project) since 1963. An intensive water quality sampling survey was conducted in 1963 and 1964 in the Lower Basin. A similar survey was made in the Upper Basin in 1965 and 1966. These surveys were designed to define the location and magnitude of all significant salt sources. In the Lower Basin, available water quality data was limited in a number of areas and an accurate evaluation of salt sources was not possible. Thus, the 1963-1964 investigation was the first attempt to accurately quantify Lower Basin salt sources.

The Geological Survey made an analysis of existing water quality data for the Upper Basin which was published in 1965.(9)(10) Their report contained the first summary of the location and magnitude of salt sources in the Upper Basin and a comprehensive compilation of available data, and provided valuable information concerning hydrological and geological conditions contributing to high salt loadings. The 1965-1966 Project investigation supplemented the Geological Survey analysis by conducting more intensive quality sampling in a number of areas to better define specific locations of salt sources and by furnishing an additional check on Geological Survey estimates of the magnitude of those salt sources for which only limited data was available.

Data developed by the various investigations discussed above and by other short term surveys of specific salt sources provided the basis for estimates of the potential salt load reductions discussed in a later chapter. A detailed evaluation of the water quality data collected by the Project is presented in Appendix A.

Preliminary feasibility studies of several potential salinity control projects and control methods were made by the Project during 1964-1965. These studies provided an indication of the potential physical features and estimated costs of a limited salinity program. Since an evaluation of the economic impact of changes in salinity concentrations was not yet available, the economic feasibility of such a program could not be determined. Recently, available information and changing water resource development plans have invalidated some of the results of the feasibility studies. However, data developed by these studies were useful for estimating the potential for control of several salt sources. Study results were available in open file reports located in the Project office in Denver.

Early in FY 1968, the FWQA and the Bureau of Reclamation initiated a cooperative salinity control reconnaissance study in the Upper Basin to identify controllable sources of salinity, determine technically feasible control measures and estimate their costs. The first year of this study was financed by a transfer of funds from FWQA to the Bureau, and the second year was financed by the Bureau. A shortage of funds forced discontinuance of the study at the beginning of FY 1970. A report entitled "Cooperative Salinity Control Reconnaissance Study, Upper Colorado River Basin," presenting the results of the study is scheduled for release during 1970.

Reconnaissance level preliminary plans were developed by the cooperative study for two salinity control projects and cost estimates prepared for a number of control measures. A preliminary Project plan was developed which would eliminate the heavy pickup of salt by the Dolores River as it crosses a salt anticline in Paradox Valley in western Colorado. A detention dam to reduce peak flood flows and a concrete channel to flume the stream through the valley would be utilized to control this source. Details of the project are discussed in Chapter V. Average annual costs of the project were estimated to total about four dollars per ton of salt removed from the river system. By way of comparison, salinity control benefits are estimated to range from about five dollars per ton of salt removed in 1970 to twelve dollars per ton in the year 2010. This project would thus appear to be economically feasible.

A preliminary plan was also prepared for a project to control the salt load from Crystal Geyser, an abandoned oil test well which periodically discharges highly mineralized water in much the same manner as a geyser. Control would be achieved by collecting the geyser discharge and pumping it to a lined impoundment for evaporation. Average annual costs were estimated to total about five dollars per ton of salt removed. A project of this type would be potentially applicable to control of some of the more concentrated mineral springs if suitable land areas for evaporation ponds can be found and evaporation rates are high enough.

For control of irrigation return flows, the costs of impounding and evaporating the flows at two topographically different sites were estimated. Annual costs of such controls would appear to be in the range of $7 - $15 per ton of salt removed. Deep well injection of relatively small quantities of the more concentrated return flows was estimated to cost about $10 - 15 per ton of salt removed. The feasibility of controlling irrigation return flows by evaporation or deep well injection would appear to be marginal on the basis of salinity control benefits alone.

The cost of lining canals and distribution systems in several existing irrigation projects as a salinity control measure was also investigated. Construction costs of such lining was estimated to range from $200 - $550 per acre, depending upon the complexity of the conveyance system. These costs are not readily convertible into a cost per ton of salt removed as the effectiveness of this control measure has not yet been fully evaluated. A canal lining demonstration project to provide the basis for such an evaluation is currently underway and is discussed in the following section.

Following a discontinuance of the cooperative study at the start of FY 1970, the Project initiated a preliminary study of a project to control the salt load from several large mineral spring areas in the vicinity of Glenwood Springs, Colorado. This study has been completed and an open file report is in preparation. Details and feasibility of this project are discussed in Chapter V.

A preliminary study of control measures for LaVerkin Springs, a large thermal spring discharging significant quantities of radium-226 and mineral salts to the Virgin River in Southern Utah, was initiated by the Project in March 1970.

RESEARCH AND DEMONSTRATION ACTIVITIES

A number of research and demonstration projects are presently underway which are expected to contribute significantly to the development and/or evaluation of various salinity control measures. Three projects are directed toward the development of techniques for minimizing salinity contributions from irrigated agriculture including a demonstration of the salinity control potential of lining irrigation canals and distribution systems. Another research project just completed has demonstrated the application of the analog computer to the simulation of the salt flow system in the Upper Basin. A fifth project recently initiated will evaluate the movement of salts in a groundwater system. These five projects were financially supported by the FWPCA. Additional research sponsored by various universities in the western states is expected to contribute improved salinity management technology. Various research projects have been proposed which, if funded and carried to completion, would substantially increase the store of salinity control technology. The following paragraphs outline the status of current activities, discuss significant research results and their application, and outline the areas of greatest need for additional salinity control research.

A research project entitled "Quality of Irrigation Return

Flow" was initiated during FY 1969 by Utah State University at Logan, Utah, under a FWQA research grant. This project has the dual objectives of increasing the knowledge of basic processes controlling the movement of salts in solids and the application of this knowledge to the development of salinity control measures. Research to date has been conducted on a small scale in the laboratory and in greenhouse lysimeters. A digital simulation model is being developed to accurately predict the movement of salts and changes in the quality of applied irrigation water within the soil and root zone. This model will be utilized to design on-farm irrigation practices, such as rate and timing of irrigation applications, so as to manage the salinity concentration of soil moisture in the root zone within acceptable limits for the specific crop being grown while minimizing the salt load contributed by the farm. This model will be refined in the future to optimize the on-farm irrigation practices of an entire irrigated area in such a manner that high irrigation efficiencies would be obtained, a salt balance would be maintained in the root zone and the pickup of additional salts from the soil profile would be minimized.

Preliminary research results indicate that it may be feasible to seasonally store salts contained in the applied irrigation water in the lower soil zone during low streamflow periods and then leach these salts out during normal or high streamflow periods. Such salt storage would help reduce the wide seasonal variations in stream salinity concentrations presently occurring in much of the Upper Basin.

The University has established a 40-acre test farm in Ashley Valley near Vernal, Utah, to provide full scale field testing of laboratory results. Field tests will be conducted during 1970 and 1971. Establishment of the test farm in this location will demonstrate salinity control measures under conditions similar to those found in many Upper Basin irrigated areas.

In response to a request from the FWPCA, a large scale research project entitled "Prediction of Mineral Quality of Return Flow Water from Irrigated Land" was initiated by the Bureau of Reclamation in the latter part of FY 1969 with financial support provided by a transfer of funds from the FWPCA.(11) The primary objective of this project is to develop a digital simulation model which will accurately predict the quantity and quality of irrigation return flows from an entire irrigation project with known soil groundwater, geologic and hydrologic characteristics. Such a model would have several applications. The water quality impact of a proposed irrigation development could be more accurately assessed than by any presently available techniques. More importantly, the model could be utilized to evaluate the water quality effects of alternative project designs thus allowing selection of the optimal design of proposed project features in order to minimize any adverse effects on mineral quality. Another application would be the evaluation of improvements of irrigation facilities and practices in established irrigated areas aimed at reducing present high salt contributions.

Field studies will be conducted in a number of locations with various soil and geologic conditions to verify prediction techniques under a wide range of conditions. Ashley Valley, surrounding Vernal, Utah, was selected as the initial study area. Characterization studies of this area are currently underway. Initial runs of an elementary simulation model will be made during 1970 using present data. The model will be refined and additional data collected during the next three years. Field studies at other locations will be initiated at some future date.

The Utah State University and Bureau research projects are being closely coordinated. Although aimed at different objectives, these projects are complementary and data collected by each project, theoretical results and other information are being exchanged. Establishment of the Vernal test farm by the University will aid in this coordination. The simulation models being developed by the two projects differ substantially in purpose and scope. The University model is limited to on-farm irrigation practices and movement of salts within the soil zone only. It can thus optimize irrigation practices to minimize salt pickup from the soil zone of the farm only. Salt pickup from the groundwater system and the effects of off-farm water losses, such as canal seepage, on the total salt load contributed by an irrigated area are not evaluated. This model is primarily a design and farm management tool. In contrast, the Bureau of Reclamation model will simulate all water and salt movement occurring in an entire irrigation project including the groundwater system. This will provide an evaluation of the salt pickup in the groundwater system and at other off-farm locations as well as the on-farm pickup. The salinity effects of alternative designs for conveyance systems, surface and subsurface drains, etc., can thus be evaluated.

The Grand Valley Salinity Control Demonstration Project at Grand Junction, Colorado, was initiated in FY 1969 under a FWPCA demonstration grant. The objective of this project is to demonstrate the salinity control potential of lining irrigation canals and laterals. The Grand Valley is underlain by an aquifer containing highly saline groundwater. Seepage from canals and laterals contributes to the recharge of this aquifer. This recharge displaces the saline groundwater into the Colorado River, increasing its salt load. Reduction of such recharge by reducing seepage from conveyance systems is thus expected to reduce the salt load discharged to the river.

A major portion of the canals and some of the laterals serving a study area of about 4,600 acres were lined with concrete during the 1969-1970 winter season. Additional canal and lateral lining will be done during the 1970-1971 winter season. Most of the lining is being accomplished by a corporation of local irrigation and drainage districts which directs the demonstration project. Colorado State University is conducting the data collection activities and evaluation of salinity control effects under contract from the corporation. A simulation model is being developed which will evaluate the effects of changes in irrigation efficiency on salt load contributions as well as changes in seepage losses from the conveyance system. This model will allow the results of the demonstration project to be projected valley-wide upon completion of the study to form the basis for future salinity control activities in this location. Completion of the demonstration project, including all post-construction studies, is scheduled for mid-1972.

Only limited research efforts are presently directed toward defining processes controlling salt loading from natural sources. The FWPCA is providing financial support for one such effort entitled, "Electric Analog Simulation of the Salinity Flow System within the Upper Colorado River Basin", which is nearing completion at Utah State University. The results of this research will provide new information concerning the distribution of salt sources in the Upper Basin and will provide an analytical tool for evaluating the water quality effects of various salinity control measures. The final research report is scheduled for publication during 1970.

A research project entitled "Effect of Water Management on Quality of Groundwater and Surface Recharge in Las Vegas Valley", was initiated by Desert Research Institute in late 1969 under a FWPCA research grant. This project will evaluate, among other things, the movement of salts in the groundwater system and the exchange of salts between the groundwater and surface waters of Las Vegas Wash. Research results will help define the optimum approach to control of this salt source. Completion of the research effort is scheduled for mid-1973.

A cooperative regional research effort, "Project W-107, Management of Salt Load in Irrigation Agriculture", was initiated in 1969 by seven western universities and the Agricultural Research Service's U. S. Salinity Laboratory. Work underway or planned covers a wide range of salinity management aspects and should provide a number of results of applicable to Basin salinity problems. The FWPCA is participating in the coordination of this research effort.

Completion of the various research and demonstration projects currently underway will provide much new information which will be useful in the formulation of a basinwide salinity control program. However, additional research and demonstration activities are needed to develop control measures for those salt sources for which no practical control measures exist and to insure that those control measures selected for implementation in a basinwide program will be the most effective and economical. A practical means of controlling small mineral springs needs to be developed and demonstrated. Application of desalination techniques to control of salt sources in mountainous areas is severely limited by the lack of a suitable method of brine disposal. Thus, a need exists for development of brine disposal methos which can be applied in areas with high precipitation and low evaporation rates. Additional methods of controlling diffuse natural sources, the major contributor of salt loads, are needed. Significant reductions in salt loads can be achieved by improving irrigation facilities and practices only if the economic advantages of implementing such improvements can be demonstrated to the individual irrigator. A number of demonstration projects of this type are needed. Additional control measures applicable to irrigated agriculture need to be developed and demonstrated. Thus, the scope and magnitude of research and demonstration needs is large.

A number of research proposals related to salinity control have been submitted by various universities in the Colorado River Basin region. Subjects of these proposals include demonstrating the relationships that exist between irrigation practices, crop yields and the salinity of return flows· evaluation of the salinity effects of drainage system operations in the Yuma area, and determination of the relative magnitude of natural and man-made salt contributions in an irrigated area. The range of research objectives shown by projects proposed or underway demonstrate the wide range of research expertise available in the area of salinity control. Thus, the expertise required to carry out needed research efforts is available at institutions in the Colorado River Basin region.

SALINITY CONTROL PROJECTS

During the latter part of FY 1968, the FWQA made funds available and requested the Bureau of Reclamation to select a pilot project to test and demonstrate control methods for reducing salinity concentrations and salt loads in the Colorado River system. The plugging of two flowing wells, the Meeker and Piceance Creek wells near Meeker, Colorado, was selected as the pilot demonstration project. The Bureau of Reclamation contractor completed plugging the Meeker well on August 3, 1968, and the Piceance Creek well on August 9, 1968. Closing of the Meeker well reduced the sodium and chloride concentrations of the White River by over 50 and 75 percent, respectively, at the Geological Survey gage below Meeker. Plugging the Piceance Creek well decreased the sodium, bicarbonate, and chloride concentrations over 10 percent at the mouth of Piceance Creek, 13 miles downstream from the well. The salinity load of the White River and the Colorado River system was reduced by about 62,500 tons annually. This is about 19 percent of the average annual salinity load in the White River near Watson, Utah. Plugging the Meeker and Piceance Creek wells initially decreased the annual flow of the White River by about 2,380 acre-feet. It is the opinion of the Bureau's regional geologist that the flow formerly discharged from the wells will reappear through natural springs nearer the discharge area at an improved quality, and that plugging the wells will not cause a decrease of the annual flow in the White River.

Costs for plugging the two wells totaled $40,000. It is estimated that the present worth of total benefits which will accrue to Colorado River water users is approximately $7 million. This project demonstrated the economic feasibility of plugging similar flowing saline wells in addition to demonstrating significant local water quality improvement. The high benefit-cost ratio for this project would indicate that plugging wells discharging considerably lesser amounts of salt would be economically feasible.

Another flowing well near Rock Springs, Wyoming, which contributed approximately 5,000 tons of salt annually, was plugged in November 1968, under the direction of the Wyoming State Engineer. The effects of eliminating this salt source have not been evaluated.

In late 1969, the Utah Oil and Gas Commission plugged seven abandoned oil test wells near Moab, Utah. This action eliminated a salt load of approximately 33,000 tons per year which was formerly contributed by two of the wells. The other five wells were not flowing. Costs of plugging the wells totaled about $35,000.

It is estimated that plugging the five flowing wells in Colorado, Wyoming and Utah will reduce the average annual salt load passing Hoover Dam by 100,000 tons or 0.93 percent. This salt load reduction would reduce average salinity concentrations by about 6 mg/l under present conditions. Although this change in salinity concentrations is small with respect to present salinity levels, the resulting economic benefits are significant. These benefits are estimated to range from $0.4 million annually in 1970 to $1.0 million annually in the year 2010 and have a present worth of more than $10 million. Thus, a modest but significant start has been made toward reducing the economic impact of rising salinity concentrations.

CHAPTER V. ALTERNATIVES FOR MANAGEMENT AND CONTROL OF SALINITY

Three basic approaches, or a combination of these approaches might be used to achieve a solution to the salinity problem: do nothing, limit development or implement salinity controls. The first approach would achieve no management of salinity control works. This approach, in effect, ignores the problem and allows unrestrained economic development at the expense of an increased adverse economic impact resulting from rising salinity concentrations.

The second approach would limit economic or water resource development that is expected to produce an increase in salt loads or streamflow depletions. Such an approach would minimize future increases in the economic impact of salinity and possibly eliminate the need for salinity control facilities. This approach has the obvious disadvantage of possibly stagnating growth of the regional economy.

The third approach, calling for the construction of salinity control works, would allow water resource development to proceed. Salinity controls would be implemented to meet a number of alternative management objectives. At least three possible management objectives could be considered: (1) salinity controls could be implemented to maintain specific salinity levels; (2) salinity could be maintained at a level which would minimize its total economic impact; and (3) salinity could be maintained at some low level for which the total economic impact of salinity would be equal to the impact that would be produced if no action were taken at all. These objectives will be discussed in more detail in later sections. This approach would require substantial expenditures for control works.

The following sections discuss an evaluation of the costs and benefits of various levels of salinity control and a comparison of the relative economics of the three basic salinity management approaches discussed above.

POTENTIAL ALTERNATIVE BASINWIDE SALINITY MANAGEMENT PROGRAMS

There are a number of technically feasible salinity control measures which could be potentially useful for management of salinity in the Colorado River Basin. Various factors, including economic feasibility, and legal and institutional constraints, limit the present practicality of many measures, and reduce the potential means of managing salinity to a few basic approaches.

The most practical means of achieving reductions in salt loads include impoundment and evaporation of point source discharges, diversion of streams around areas of salt pick-up, improvement of irrigation practices and facilities to reduce return flow volumes, desalination of saline discharges from natural and man-made sources, and desalination of water supplies at the point of use. Augmentation of streamflow can be achieved by importation of water from other basins, by importation of demineralized sea water, and by increasing precipitation and runoff in the basin utilizing weather modification techniques. The control measures could be implemented in a variety of locations and combinations to achieve basin wide management of salinity. An optimal management program would probably include each of these methods in some combination as well as other salinity control measures such as water conservation.

The following sections discuss the physical features, estimated costs, and water quality effects of eight potential alternative programs incorporating these two major management approaches. These programs included three salt load reduction programs, four flow augmentation programs, and one program to treat water supplies at the point of use. A comparison of these alternative programs indicates that a large-scale salt load reduction program would be the most economical means of achieving basinwide management of salinity. This salt load reduction program was thus selected to establish the potential scope and costs of a basinwide program designed to meet various alternative salinity management objectives discussed in a later section.

Salt Load Reduction Programs

Reduction of salt loads at their source appears to be the most practical approach to management of salinity. By preventing highly mineralized waters from reaching the stream system or by reducing the pickup of salts by high quality water, substantial reductions in salinity concentrations may be achieved at costs relatively low in comparison with most other measures. A variety of control measures would be employed by a low cost salt load reduction program. The major features of two such programs are outlined in the following paragraphs. A salt load reduction program employing desalination techniques only (resulting in higher program costs) is discussed in a later section on desalination.

Full Scale Salt Load Reduction Program--One potential basin-wide salt load reduction program was formulated which would seek to control a major fraction of the salt load contributed by five large natural sources and 12 irrigated areas. The major features of this program are listed in Table 2 with potential control project locations shown in Figure 3. The selection of salt sources to be controlled, physical features of each project, and estimates of potential costs and salt load reductions were based on the latest information available from various research, demonstration and technical investigation activities. Present salinity control knowledge is still limited, however, and a number of assumptions were required to formulate the details of the program. The cost and effectiveness of estimates assigned to each project should, therefore, be considered representative of the approximate magnitude of expected costs and salt load reductions rather than detailed estimates of actual results to be achieved. Additional research and feasibility investigations would be required to refine these estimate and verify assumptions.

For a given project, construction costs and the actual salt load reductions achieved may vary over a wide range. Bayesian statistical decision theory was utilized, as outlined in a later section on salinity management costs, to estimate the expected (mean) value of possible costs and salt load reductions for each

Table 2. Potential Full Scale Salt Load Reduction Program

Project Description			Expected Average Annual Values			
No.	Location	Features	Total Project Costs ($1000/Yr)	Salinity Control Costs ($1000/Yr)	Salt Load Reduction (1000/Yr)	Cost Index ($/T)
1.	Paradox Valley, Colo.	Stream Diversion	700	700	180	3.89
2.	Grand Valley, Colo.	Irrig. Improvements	3,140	1,570	312	5.04
3.	Lower Stem Gunnison River Colorado	Irrig. Improvements	3,600	1,800	334	5.40
4.	Price River, Utah	Irrig. Improvements	1,000	500	89	5.65
5.	Las Vegas Wash, Nev.	Export & Evaporation	600	600	100	6.00
6.	Uncompahgre River, Colorado	Irrig. Improvements	4,000	2,000	320	6.25
7.	Big Sandy Creek, Wyo.	Irrig. Improvements	490	245	39	6.28
8.	LaVerkin Springs, Utah	Impoundment & Evap.	600	600	80	7.50
9.	Roaring Fork River, Colorado	Irrig. Improvements	880	440	52	8.47
10.	Upper Stem Colorado River, Colorado	Irrig. Improvements	1,420	710	80	8.88
11.	Henry's Fork River, Utah	Irrig. Improvements	710	355	40	8.88
12.	Dirty Devil River, Utah	Irrig. Improvements	710	355	40	8.88
13.	Duchesne River, Utah	Irrig. Improvements	5,660	2,830	273	10.37
14.	San Rafael River, Utah	Irrig. Improvements	1,360	680	65	10.48
15.	Ashley Creek, Utah	Irrig. Improvements	830	415	36	11.55
16.	Glenwood Springs, Colorado	Desalination	5,000	5,000	370	13.50
17.	Blue Springs, Ariz.	Export & Desalination	16,000	16,000	500	32.00
		Program Totals	46,700	34,800	2,910	

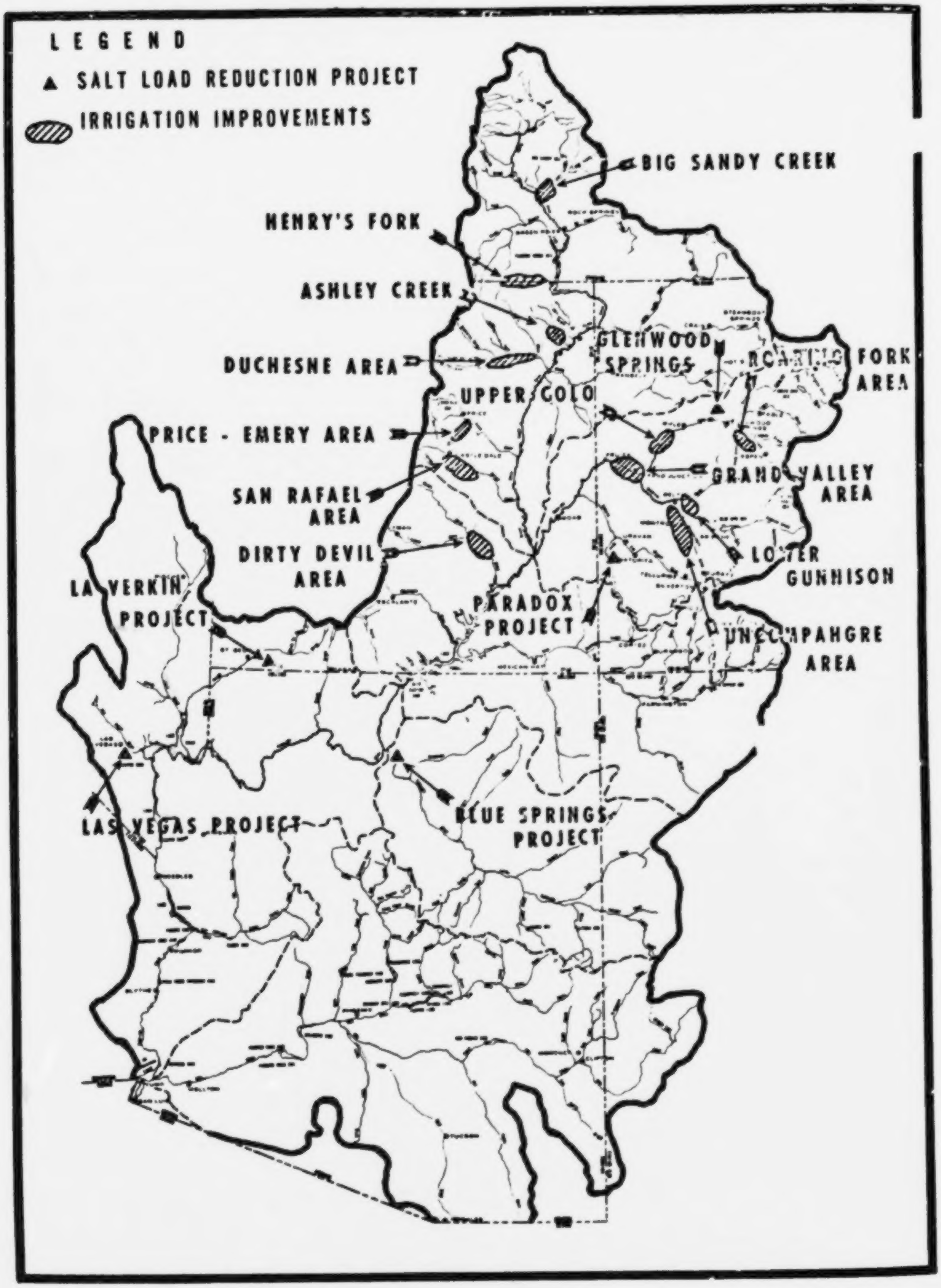
LEGEND
▲ SALT LOAD REDUCTION PROJECT
▨ IRRIGATION IMPROVEMENTS
BIG SANDY CREEK
HENRY'S FORK
ASHLEY CREEK
DUCHESNE AREA
GLENWOOD SPRINGS
ROARING FORK AREA
UPPER COLO
PRICE - EMERY AREA
SAN RAFAEL AREA
GRAND VALLEY AREA
DIRTY DEVIL AREA
LOWER GUNNISON
LA VERKIN PROJECT
PARADOX PROJECT
UNCOMPAHGRE AREA
LAS VEGAS PROJECT
BLUE SPRINGS PROJECT

Figure 3. Location of Potential Salt Load Reduction Projects

project. The costs and salt load reductions shown in Table 2 are thus the expected values of a range of possible values for each project. The total estimated project costs shown are in terms of average annual costs which include amortized construction costs, operation costs and maintenance costs. A five percent discount rate was used for all cost estimated discussed in this chapter.

The Paradox Valley, Las Vegas Wash, LaVerkin Springs and Glenwood Springs salt load reduction projects would be single purpose only. For these facilities, all project costs were considered to be salinity control costs as shown in Table 2. The Blue Springs project would be a multiple purpose facility. However since only the costs of the salinity control portions of the project were estimated, the total project costs shown in Table 2 are all salinity control costs. Improvment of irrigation practices and facilities in the 12 irrigated areas selected would produce a number of benefits in addition to salinity control benefits. These benefits are estimated to be of about the same economic magnitude as salinity control benefits. For this reason, only half of total improvement costs were designated as salinity control costs.

Five salt load reduction projects utilizing various salinity control measures were selected for control of large natural discrete and diffuse sources. The sources selected represent those for which control appears to be most practical and economical at this time. It is possible that additional technical investigations and feasibility studies could result in the formulation of other more economical control projects for other sources. Details of the five projects selected are discussed in the following paragraphs.

The Dolores River picks up a large salt load as it crosses Paradox Valley in western Colorado. This salt pickup is believed to be the result of the recharge during periods of high streamflow of a groundwater aquifer in contact with the highly saline Paradox formation. Elimination of the salt load produced by such recharge conditions may be achieved by construction of a detention dam on the Dolores River upstream from Paradox Valley for reducing peak flood flows and by construction of a concrete-lined channel four miles long to convey streamflow through Paradox Valley. A preliminary plan for this project was developed by the Bureau of Reclamation as part of the Cooperative Salinity Control Reconnaissance Study.(12)

Interception of the outflow from Las Vegas Wash in Nevada and export to a dry lakebed in a closed basin was selected as the control project for this tributary. Export of the volume of flow currently leaving Las Vegas Valley would probably not be practical. However, future conditions may be significantly different. A comprehensive water pollution control plan is being developed for the Las Vegas metropolitan area.(13) Current waste disposal proposal call for tertiary treatment of all municipal and industrial wastes with the high quality effluent piped to the Colorado River below Hoover Dam.(14) Desalination of the treated effluent might also be provided to allow a high degree of water reuse in the valley. Implementation of either a waste export or water reuse scheme would probably reduce the volume of flow in the Wash to an amount that could be economically exported. The project listed in Table 2 is based on the assumption that one of these schemes will be implemented. A research project was recently initiated by Desert Research Institute under an FWQA grant to define groundwater conditions in lower Las Vegas Valley. The final plan selected for regional waste disposal facilities and the results of the groundwater research will probably determine the final design of a control project for this salt source.

LaVerkin Springs are located in the Virgin River Basin in southern Utah. In addition to being a large salt source, these springs also discharges significant quantities of radioactive radium salts. Control of a major portion of the springs discharge could potentially be achieved by gravity conveyance to a large, lined pond for evaporation and storage. Concentration of the radium salts through evaporation could pose a potential radioactivity hazard. Commercial recovery of the radium may be potentially feasible, eliminating this hazard. Control of this salt source would produce significant local benefits as a result of reduced salinity in the irrigation supply for the Bureau of Reclamation's proposed Dixie Project and other local irrigation areas.

A number of large mineral springs and seeps, including Dotsero Springs, Yampa Springs, and Glenwood Springs, are located along a 20-mile-long reach of the Colorado River near Glenwood Springs, Colorado. A reconnaissance study of this large salt source recently completed by the Project, showed that a large fraction of the combined spring flow could potentially be intercepted and conveyed to a central location.(15) A 16-mgd desalination plant could then be utilized to demineralize the collected flow with pure water returned to the river system. The concentrated brine could be disposed of by deep-well injection into a salt formation. No local market for the demineralized water now exists. However, should development of the oil shale deposits in the area materialize, the demineralized water could possibly be sold for municipal or industrial use to provide a source of income to offset part of the project costs. Sale of the concentrated brine for industrial use is another potential source of income.

Control of the major salt load contributed by the Little Colorado River, including the discharge of Blue Springs, would require the construction of a complex facility. The control works envisioned would be multiple-purpose and would include such major project features as a multi-stage, underground pumped storage hydroelectric plant located near the mouth of the Little Colorado River, a 250 cfs pumping plant located near the upper reservoir of the hydroelectric plant located near Flagstaff, a large-scale nuclear power plant including a 200-mgd desalination facility, and brine disposal facilities. Such a project would capitalize upon the expanding demands for electric power in the Southwest and the water needs as a result of multiple use of facilities. A major portion of project pumping could be achieved during off-peak at low power costs. Sale of demineralized water to municipal and industrial water users in Central Arizona by discharge to the Verde River system would offset about half of the estimated desalination costs, thus reducing salinity control costs. The costs shown in Table 2 for this project include estimates for the aqueduct, pumping plant, desalination facility, and brine disposal facilities only. Costs were not estimated for the major hydroelectric and nuclear power facilities as these would not be directly related to salinity control.

Several factors control the feasibility of constructing a project of this magnitude. Perhaps the most serious potential limitation would be the relationship of this project and the Central Arizona Project with regard to Arizona's allotment of Colorado River water. If Colorado River flow is not augmented, delivery of 150,000 acre-feet annually from the Little Colorado River would require reducing the delivery of the Central Arizona Project by a like amount. Thus, that project's financing would be affected.

A second major factor is the need to sell the entire project concept to a major power company or consortium. The need for both base and peaking power production in this area has been shown by proposals for large-scale peaking power production at the Bridge Canyon Dam and proposals for large-scale fossil fuel power facilities near Four Corners and other nearby locations. A potential demand for large power projects thus appears to exist.

A major portion of the salt load reduction effected by a full-scale basinwide program would be achieved by control of salt loads contributed by irrigated agriculture. Twelve large irrigated areas contributing the highest salt loads in the basin (three to six tons per acre per year) were selected for implementation of control measures. The total irrigated area of about 600,000 acres included in these 12 areas is only about 20 percent of the irrigated acreage in the basin but contributes more than 70 percent of the salt load attributed to irrigation sources.

Most of the irrigated areas selected have similar soil and geological conditions. The soils contain relatively high amounts of soluble salts and are generally underlain by moderately saline, shallow groundwater systems and highly saline shales or lacustrine formations. Under such conditions, excessive applications of irrigation water, poor irrigation efficiencies, conveyance system losses and other water losses result in large volumes of return flows which pick up salts from the soils and underlying formations. Control measures would be directed toward reducing such return flows. Due to slight variations in soil and geological conditions, the present condition of irrigation facilities, present levels of irrigation efficiency, and other variation between areas, the magnitude and scope of control measures would differ from area to area.

Estimates of the costs and salinity control effectiveness of the irrigation improvements selected for control measures were based on preliminary results of various research efforts currently underway. Installation of varying amounts of canal lining and distribution system improvements, closer control on water deliveries, modification of irrigation practices to substantially improve irrigation efficiencies, installation practices to substantially improve irrigation efficiencies, installation of some sub-surface drains, and other irrigation improvements would be required to achieve estimated levels of salt load reduction. These improvements would also produce a number of direct benefits to water users and irrigation districts in the form of water conservation, reduced maintenance costs, increased crop yields, and reduced fertilizer costs. These benefits are estimated to be of about the same magnitude as salinity control benefits. For this reason, only 50 percent of the total costs of irrigation improvements were designated as salinity control costs as shown in Table 2. Improvement of irrigation facilities and practices as proposed would require a great deal of local cooperation and a substantial local investment. Local educational programs would need to be expanded to teach irrigators how to improve their practices. More importantly, demonstrations of the economic feasibility of such improvements would be required to induce the irrigators to make the necessary local investment in facility improvements.

When completely implemented, it is estimated that the full-scale program outlined in the previous paragraphs and tabulated in Table 2 would achieve a total potential salt load reduction of 2.9 million tons annually at Hoover Dam. This represents a 27 percent reduction in the average annual salt load passing Hoover Dam for the 1942-1961 period of record adjusted to 1960 conditions of water use. Implementation of the full program in the period from 1975 to 1980 would result in reductions in predicted average salinity concentrations at Hoover Dam from 876 mg/l to 623 mg/l in 1980, and from 990 mg/l to 715/l in 2010. Average annual program costs, including amortized construction costs, operation costs and maintenance costs, are estimated to total $34.8 million. The 1970 present worth of total salinity control costs for this program for the period from 1975 to 2010 is estimated to be $375 million assuming a five percent discount rate.

Incremental Salt Load Reduction Program--Since the full scale program previously discussed is made up of a number of independent control projects, a number of alternative programs could be formulated by varying the time scale for implementing the individual projects. One such alternative program is discussed in the following paragraphs.

Implementation of the full-scale program by 1980 would reduce salinity concentrations at Hoover Dam below average concentrations for 1960 conditions of water use (697 mg/l) until beyond the year 2000. Achieving this degree of water quality enhancement would require a heavy expenditure of construction funds over a short time period. An alternative plan to lengthen the implementation period could be formulated which would also achieve significant water quality enhancement. By phased or incremental implementation of the full scale program, a constant salinity level of 700 mg/l to approximate 1960 conditions could be maintained. A salt load reduction of 2.1 million tons per year in 1980 and 3.2 million tons per year in 2010 would be required to maintain this salinity level. Implementation of the first 13 projects listed in Table 2 would be required by 1980 to achieve this salt load reduction in 1980. Gradual implementation of the remaining four projects in the period 1980-2000 would be required to maintain the constant salinity level. A salt load reduction of 0.3 million tons per year would be required in 2010 in addition to implementation of the full scale program in order to maintain the 700 mg/l salinity level. In order to estimate program costs, it was assumed that additional control projects could be formulated in the future to achieve the added reduction for unit costs comparable to average program unit costs.

Average annual salinity control costs of the 13 projects to be implemented by 1980 were estimated to total $12.7 million. Average annual costs would increase with time as additional control measures are implemented reaching an estimated $39.4 million in 2010. The 1970 present worth of total salinity control costs for this phased implementation of a salt load reduction program over the period from 1975 to 2010 is estimated to be $230 million. Total costs of a program implemented in increments as discussed are thus substantially less than for immediate implementation of a full scale program.

Flow Augmentation Programs

A second means of effectively reducing salinity concentrations would be to dilute existing streamflow with high quality water. For the Colorado River Basin, such flow augmentation could potentially be obtained from three sources - weather modifications, interbasin transfer, and desalination of sea water. A number of schemes have been proposed which would utilize these sources to provide varying amounts of flow augmentation. The costs and salinity control potential of three such schemes are discussed in the following sections. A fourth scheme utilizing demineralized sea water as a flow augmentation source is discussed in a later section entitled desalination programs.

Weather Modification Program--Increasing the runoff in the Basin by stimulating precipitation through utilization of weather modification techniques is one potential means of augmenting streamflow. The Bureau of Reclamation has estimated that as much as 1.87 million acre-feet of additional streamflow could be made available in the Upper Basin by a full-scale weather modification program at an annual cost of $2.65 million.(6) The salinity control effects of such a program will vary depending upon the locations at which the supplemental supply would be utilized. If the additional supply was consumptively used in the Upper Basin, the salt load in the Lower Basin would be increased without accompanying dilution and the salinity problem would be compounded. If the entire supplemental supply was consumptively used in the Lower Basin however, it would result in substantial reductions in salinity concentrations.

The United States is required by the Mexican Treaty to deliver 1.5 million acre-feet of Colorado River water to Mexico annually. Meeting this treaty requirement has been declared a national obligation. The estimated volume of flow potentially available from a weather modification program is about equal to the amount that would be required to offset a proportionate amount of reservoir evaporation and river system losses and deliver 1.5 million acre-feet to Mexico annually. Thus, a potential use for the increased supply would be to provide the required Mexican deliveries. Utilization of the water in this manner would significantly reduce salinity concentrations throughout the lower river system.

Weather modification activities would be aimed primarily at augmenting snow accumulations in high mountains areas. The resulting increases in runoff would be primarily in the form of high quality Spring snowmelt. This Spring runoff would normally reach Lake Mead with a salinity concentration of about 300 mg/l. This concentration was used to estimate the increase in salt burden that would accompany the additional streamflow.

Assuming that the additional streamflow passing Hoover Dam would average 1.7 million acre-feet annually, flow augmentation from this source would reduce predicted average salinity concentrations at Hoover Dam from 876 mg/l to 783 mg/l in 1980 and from 990 mg/l to 870 mg/l in 2010. At an average annual cost of $2.65 million, the present worth of weather modification program costs from 1975 to 2010 was estimated to be $32 million.

Augmenting streamflow would produce substantial direct benefits in addition to salinity control benefits. These benefits, such as increased power production, increased water supply, etc., were not evaluated but are known to have a large economic value. If program costs were allocated in proportion to resulting benefits, as was done for irrigation improvements as discussed in a previous section, the costs assigned to salinity control would probably be less than half of total costs. Weather modification may therefore be the most economical means of achieving salinity control. The magnitude of control that can be achieved in this manner is limited, and the practicality of weather modification has not been demonstrated. If weather modification becomes practical, a combination of flow augmentation from this source and the more economical elements of the salt load reduction program could achieve a high degree of salinity control for moderate costs.

Limited Interbasin Transfer--It is possible that augmenting streamflow with larger volumes of water than the estimated volumes available from weather modification could eventually be achieved by interbasin transfer of high quality water. A number of schemes have been proposed by public and private interests which would import varying volumes of high quality water from a variety of different sources.(19) The salinity control effects of these various schemes are dependent upon the quality of the import water, the point of importation into the Basin, and the locations of ultimate consumptive use as discussed in the previous section on weather modification. Since a significant salt load will also be imported into the Basin, the point of ultimate use becomes a very important factor in the degree of salinity control that can be achieved.

Several of the proposed transfer schemes would import water directly to Lake Mead. If an annual volume of 2.5 million acre-feet were imported to Lake Mead at a salinity concentration of 300 mg/l (representative of the quality of proposed sources when transmission loss effects are considered) and this increased supply was utilized in the Lower Basin, predicted average salinity concentrations at Hoover Dam would be reduced from 876 mg/l to 749 mg/l in 1980 and from 990 mg/l to 827 mg/l in 2010.

No detailed cost estimates are available from which the average annual costs of a limited interbasin transfer program could be determined. If a cost of $30 per acre-foot of water imported is assumed, average annual program costs would total $75 million. Assuming that the necessary facilities could be constructed between 1975 and 1980 (a very optimistic assumption), the present worth of program costs from 1975 to 2010 was estimated to be $800 million.

Augmenting streamflow by interbasin transfer would also produce substantial benefits in addition to salinity control benefits as discussed in the previous section on weather modification. Evaluation of these benefits is beyond the scope of the investigations undertaken by the Project. These benefits are known to have a large economic value and would probably reduce the fraction of program costs which would be allocated to salinity control to less than half.

Large-Scale Interbasin Transfer--Projections of future water demands in the Lower Basin indicate that an increase in water supply of more than 2.5 million acre-feet annually could be utilized. Several of the proposed transfer schemes would seek to meet this larger water demand. Large quantities of water would be available from these schemes for achieving substantial dilution and salinity control. Various levels of salinity control could thus be achieved by supplying larger volumes of flow augmentation.

For purposes of comparison with the salt load reduction program previously discussed, the volume of flow augmentation required to maintain a constant salinity level of 700 mg/l at Hoover Dam was determined. Assuming the imported water would have a salinity concentration of 300 mg/l, it is estimated that flow at Hoover Dam would need to be augmented by 3.9 and 5.9 million acre-feet annually in 1980 and 2010 respectively, to maintain a constant salinity level of 700 mg/l.

Again, assuming a cost of $30 per acre-foot, the average annual costs of such an importation program are estimated to total $117 million and $177 million in 1980 and 2010, respectively. With an optimistic implementation period of 1975 to 1980, the present worth of total program costs from 1975 to 2010 was estimated to be $1,470 million.

This flow augmentation scheme would also produce substantial benefits which would reduce costs allocated to salinity control as discussed in the previous section.

Other alternative flow augmentation program of the type just discussed could be formulated to meet other water quality goals. The volume of flow augmentation required and total program costs would vary inversely with the target salinity concentration at Hoover Dam.

A third possible source of flow augmentation is demineralized sea water. Desalination plants located near the Gulf of California or the Pacific Ocean could provide a supply of high quality water for direct use in southern California or Mexico, or for augmentation of the Lower Colorado River. The Bureau of Reclamation has conducted a feasibility study of one such augmentation scheme. The results of the study are discussed in the following section on desalination.

Desalination Programs

Desalination installations could potentially be utilized to remove salt loads at their source, to reduce the salinity of a water supply at the point of water use, and to provide a source of high quality water for flow augmentation. Three alternative programs which utilize desalination technology are discussed in the following sections.

Source Control Program--In contrast to the salt load reduction programs previously discussed which utilize a variety of control measures, a comparable source control program could be formulated which would utilize desalination plants only as the control measure. The plants would function to remove the salt load from such concentrated sources as mineral spring discharges, saline tributaries and irrigation return flows. Due to the scattered locations and relatively small magnitude of the various salt sources suitable for demineralization, a large number of small desalination plants would be required to achieve any substantial reduction in salt loads. The unit costs of operating such small plants are high.

Another factor affecting the economy of such a program is the lack of highly saline sources for demineralization. Some mineral springs in the Basin discharge water with salinity concentrations exceeding 20,000 mg/l, but the volumes of such highly saline flows are small. Much of the Basin's salt load is contributed by irrigation return flows and other discharges with concentrations below 4,000 mg/l. A detailed evaluation has not been made of the locations, magnitudes and salinity concentrations of sources suitable for desalination. Thus, an accurate determination cannot be made at this time of the volume and average concentration of the flow that would need to be demineralized to achieve a given salinity control objective.

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However, utilizing several assumptions, it is possible to evaluate the approximate magnitude of a desalination program.

Supply Treatment Program--A major portion of the economic impact of future salinity increases could be eliminated by reducing salinity levels in the water supply diverted to southern California through the Colorado River Aqueduct and All American Canal. Desalination plants at Parker and Imperial Dams could be utilized to remove a portion of the diverted salt load and maintain desired salinity levels. These plants would be large scale and could operate more economically than the small scale plants utilized in the source control program. Also, brine disposal would be less of a problem at these desert locations. Due to the low concentration of the supply water (less than 1,500 mg/l) the volumes of flow demineralized would be large and total costs would be high.

To maintain a salinity concentration of 700 mg/l in the diverted flow would require the desalination of an estimated 1.4 and 1.6 million acre-feet annually in 1980 and 2010 respectively. At an estimated unit cost of $100 per acre-foot ($0.30 per 1,000 gallons), average annual program costs would total $140 million in 1980 and $160 million in 2010. Assuming a 1975 to 1980 implementation period, the present worth of program costs from 1975 to 2010 was estimated to total $1,570 million.

A supply treatment program would be single purpose and all costs would be allocated to salinity control.

Flow Augmentation Program--Demineralized sea water is another potential source for augmenting streamflow in the Lower Colorado River. The Bureau of Reclamation has conducted a reconnaissance study of one scheme to import demineralized sea water. (4) The source would be a large scale nuclear power and desalination facility located on the Pacific Ocean between Los Angeles and San Diego. A large aqueduct would convey the demineralized water overland to Hoover Dam. As investigated by the Bureau, this scheme would be constructed in stages and would provide 1 million acre-feet of flow augmentation in 1990, increasing to 2 million acre-feet in 2010. Average annual program costs were estimated to total $131 million.

If the full 2 million acre-feet of flow augmentation were made available in 1980, average salinity concentrations at Hoover Dam would be reduced to 710 mg/l and 740 mg/l in 1980 and 2010, respectively. On the basis of implementation between 1975 and 1980, the present worth of total program costs from 1975 to 2010 was estimated to be $1,400 million.

Such a flow augmentation scheme would increase the available water supply for salinity control and provide substantial multiple purpose benefits. Other flow augmentation schemes involving demineralization would also provide multiple purpose benefits; however, the extent to which these benefits would reduce the costs allocated to salinity control was not evaluated.

Comparison of Alternatives

The eight alternative salinity control programs discussed in the previous sections are not directly comparable. Variations in the magnitude and scope of the alternatives result in differences in the level of salinity control achieved. Also, some of the programs are single-purpose with all costs assignable to salinity control while other programs are multiple-purpose with substantial benefits from other than salinity control to offset part of the program costs. It is possible to make comparisons between similar alternatives and to select the alternative which appears to be the most economical for achieving basinwide management of salinity.

The estimated costs and salinity control effects of the eight alternative programs are summarized in Table 3 Salinity concentrations expected, if no controls are implemented, are also shown in the table for comparison purposes. Comparisons of similar alternatives and the basis for selection of the phased implementation of a salt load reduction program as the least cost alternative salinity control program are presented in the remainder of this section.

The first two alternatives programs listed in Table 3 are composed of identical salt load reduction measures and differ only in the timing of implementation. Alternative number one would implement the full program by 1980 while the second alternative would delay full implementation until about 2000. Salinity control and other benefits produced by early

Table 3. Comparison of Alternatives Salinity Control Programs

No.	Alternative Salinity Control Program	Average Salinity Concentrations at Hoover Dam		Average Amount Program Cost		Present Worth
		1980 (mg/l)	2010 (mg/l)	1980 ($ Million/Yr)	2010 ($ Million/Yr)	($ Million)
1.	Salt Load Reduction (Full scale implementation)	620	720	47	47	510
2.	Salt Load Reduction (Phased Implementation)	700	700	23	52	350
3.	Flow Augmentation (Weather Modification) (1.7 MAF/Yr)	780	870	3	3	30
4.	Flow Augmentation (Interbasin Transfer) (2.5 MAF/Yr)	750	830	75	75	800
5.	Flow Augmentation (Interbasin Transfer) (3.9-5.9 MAF/Yr)	700	700	118	177	1,470
6.	Desalination (Source Control)	700	700	41	62	510
7.	Desalination (Supply Treatment)	--	--	140	160	1,570
8.	Desalination (Flow Augmentation) (2.0 MAF/Yr)	710	740	131	131	1,400
9.	No Salinity Control	876	990	--	--	--

implementation do not justify the substantial difference in program costs. Therefore, alternative number two, phased implementation of a salt load reduction program, would be the most economical program.

Alternative number six, a source control program utilizing desalination techniques, is a single-purpose alternative which would produce salinity control effects identical to alternative number two. Since resulting program benefits would be less (no benefits in addition to salinity control) and program costs higher than alternative number two, the latter remains the least cost alternative.

The supply treatment program (alternative number seven) would not control salinity levels in all water supplies in the Lower Basin. This alternative would thus produce fewer benefits than alternative number six which is similar. Alternative number seven has a higher cost than number six and is therefore inferior economically.

The remaining four alternatives, numbers 3,4,5, and 8, all would increase the Basin in water supply to some degree and would produce substantital benefits in addition to salinity control benefits. These additional benefits have not been qualified, as such an evaluation was beyond the scope of Project investigations. These four alternatives are thus not directly comparable to the four previously discussed. A comparison can be made between the four flow augmentation programs, and the less economical programs eliminated.

A desalination program and a limited interbasin transfer program would provide about the same amounts of flow augmentation. Water supply benefits would be comparable for both programs. Salinity control achieved by importation of demineralized water would be greater than for importation of normal fresh water, however, the resulting difference in salinity control benefits would not justify the differences in program costs. Alternative number 4, the limited interbasin transfer program would thus appear to be superior to alternative number 8, the desalination program.

Alternative numbers 4 and 5 differ both in the amount of flow augmentation provided and in the degree of salinity control achieved. If it is assumed that water supply benefits are proportional to the amount of flow augmentation provided, the large scale program should produce about double the benefits of a limited program. The salinity control benefits of the large scale program would also be greater than for a limited program. Since the costs of a full scale program average less than half of those for a limited program, the large scale program, alternative number 5 should produce a greater net economic return and would be superior to alternative number 4.

A large scale flow augmentation program (alternative number 5) would produce the same level of salinity control, hence the same salinity control benefits, as the phased salt load reduction program (alternative number 2). These two alternatives are thus directly comparable with regard to salinity control.

However, program costs and the magnitude of additional benefits associated with the two programs are vastly different. Selection of the most economical alternative with respect to salinity control is therefore dependent upon the relative magnitude of other program benefits and resulting allocation of costs to salinity control. For the salt load reduction program, the present worth of salinity control costs was estimated to be $230 million. This amount is about 15 percent of the present worth of total program costs for large scale flow augmentation. Non-salinity control benefits would have to exceed 85 percent of total benefits before flow augmentation would become more economical. Because of the large difference in total program costs and a low probability that the necessary benefits ratio would be achieved, the salt load reduction program was selected as the least cost alternative.

The time required for implementation of control measures is another factor that supports the selection of the salt load reduction program. For purposed of comparison, an implementation period of 1975 to 1980 was assumed for all alternatives. With optimum progression of necessary studies, fund appropriations, etc., the initial phases of the salt load reduction program could be implemented by 1980. Such optimism is not realistic for large scale public works as envisioned for the flow augmentation program. A date of 1990, or 2000 would be more realistic for delivery of large volumes of water from another basin. Substantial increases in salinity levels and attendant economic impact would thus occur before control of salinity by flow augmentation could be achieved.

A flow augmentation program utilizing weather modification techniques (alternative number 3) is not directly comparable to any other alternative. The salinity control that could be achieved by such a program is limited as are the salinity control benefits. For the level of control achieved, however, weather modification has the lowest unit costs. Substantial water supply benefits would also accrue to the program reducing costs allocated to salinity control. The practicablility of basinwide weather modification has not been demonstrated. For this reason and because of the limited degree of control that could be achieved, weather modification was not considered a practical alternative. Should the practicality of this approach be demonstrated in the future, a combination of a weather modification program and the more economical elements of a salt load reduction program would result in the minimum cost for achieving moderate levels of salinity control. Utilizing this combination to maintain a constant salinity level of 700 mg/l at Hoover Dam would result in a reduction of about one-third in total salinity control costs for the salt load reduction program alone.

In summary, on the basis of present knowledge of the technical feasibility, costs and practicality of various salinity control measures, the phased implementation of a salt load reduction program (alternative number two) appears to be the most economical and practical means of achieving basinwide management of salinity. This alternative was therefore utilized as the basis for estimates of salinity management and total salinity costs discussed in a later section on economic aspects. The following section discusses several other factors that should receive consideration in the final formulation of an optimal basin-wide salinity management program.

Other Considerations

Diurnal, seasonal, and other short-term cyclical fluctuations in salinity concentrations occur throughout the basin. The fluctuations are the result of a number of natural and man-made factors including seasonal variations in streamflow, droughts, reservoir operations, irrigation system operations, etc. Present peak salinity concentrations occurring during such fluctuations in the Lower Colorado River are approaching critical levels for some types of salt-sensitive crops. Should these high concentrations be maintained for longer periods of time than at present as the result of severe drought or other factors, significant damage to such crops could occur. Some types of crops are most sensitive to high salinity levels during the germination period. The occurrence of short-term high peak concentrations during the period when seed beds are being irrigated could result in heavy damage to that crop even though average salinity concentrations during the irrigation season were lower.

The salinity control measures incorporated in the salt load reduction program previously selected as the best alternative for basinwide salinity control are designed primarily to reduce long-term average salinity concentrations. By reducing the salt burden carried by the river system during low flow periods, partial control of peak concentrations would also be achieved. In view of the potential economic impact on water users, however, more positive means of controlling short-term fluctuations should be sought.

One potential means of minimizing short-term salinity fluctuations would appear to be the manipulation of reservoir storage and releases. Prior to the construction of Hoover Dam, salinity concentrations in the Lower Colorado River fluctuated widely from season to season and from year to year. The large volume of storage in Lake Mead has substantially dampened out these fluctuations. Lake Powell is expected to produce a similar dampening action. These large reservoirs do not produce a complete mixing of low and high quality inflow however, due to their long, narrow configurations. Consequently, Lake Mead has historically exhibited a tendency to pass higher salinity inflows, resulting from low runoff years, through the reservoir with relatively small reductions in peak concentrations. Reduced outflow from Lake Powell during periods of low inflow, in combination with large salt loads contributed by sources located between Lake Powell and Lake Mead, could result in short-term fluctuations in the salinity of Hoover Dam releases similar to those occurring prior to closure of Glen Canyon Dam. The potential for utilizing storage in Lake Powell and Lake Mead and coordinating releases from these reservoirs to minimize short-term salinity fluctuations should be investigated.

The fluctuating streamflow inherent in the operation of the various power plant, irrigation diversions, irrigation projects, etc., located along the Lower Colorado River in combination with the relatively uniform contribution of saline irrigation return flows are believed to be the source of significant short-term flucutations in salinity concentrations at Imperial Dam. Close coordination of all water operations, such as computer scheduling of on-farm irrigation deliveries and computer control of automatic flow controls, should be investigated as a potentially feasible means of eliminating such fluctuation.

Manipulation of reservoir storage and close coordination of water movements would appear to show substantial promise for minimizing fluctuations in the Lower Basin. In the Upper Basin, a lack of adequate storage for regulation of water movements on many tributaries would preclude control of fluctuations in this manner. One method which may be applicable in the Upper Basin is the seasonal storage of salt within the soil column in irrigated areas. The volume of salt reaching the river system during low flow periods could be reduced by this method thus reducing peak salinity concetrations. Salt balance would be maintained by leaching out the stored salt during periods of high runoff. This control method is currently under investigation at Utah State University as discussed in Chapter IV.

There are no water quality simulation models presently available which could be utilized to accurately predict the magnitude and timing of salinity fluctuations. Present methods of evaluating the economic impact of salinity on water users utilize long-term salinity concentrations and cannot evaluate the economic impact of short-term fluctuations. This analytical capability needs to be developed before the economic feasibility of controlling fluctuations can be assessed.

There are also a number of long-term salinity control measures which have not been evaluated for economic feasibility. Such measures as water conservation, cessation of irrigation of highly saline soils, etc., may have a definite place in an optimal salinity management program. Development of such a program should give careful consideration to all potential control measures.

One other area that should be investigated is the exchange of water at locations both in and out of the basin. For example, it might be possible to provide demineralized sea water to southern California in exchange for water presently diverted from the Colorado River. The water supply and water quality effects of such an exchange should be evaluated as a basis for comparison with other alternatives previously discussed.

ECONOMIC ASPECTS

There are various economic costs associated with the use of a degraded water supply. Direct costs are incurred by water users. In addition, the regional economy suffers economic losses stemming from these direct costs. There are also costs associated with the control and management of salinity. Together, these costs constitute the total economic impact of salinity variations in terms of total costs corresponding to changes in salinity concentrations and thereby provide the basis for determining the economic feasibility of salinity control. The main components of salinity costs are discussed in the following sections.

Salinity Detriments

Salinity detriments are the costs associated with *use* of a water supply of a given salinity concentration and consist of two major components, direct detriments and indirect detriments. Direct detriments are the costs incurred directly by the water users and may take such forms as descreased crop yields, increased municipal and industrial water treatment costs, pipe corrosion, increased consumption of soaps and laundry additives, etc. Indirect detriments are the economic losses suffered by the regional economy which stem from the direct detriments. Different methods of analysis must be employed to determine these two component costs. Determination of the magnitude of direct and indirect detriments is discussed in the following sections.

Determination of Direct Detriments-- A detailed study of water use in the Lower Colorado River Basin and southern California water service area for present and future conditions provided the basis for determination of direct detriments. The Southern California water service area includes Imperial and Coachella Valleys and those portions of the Los Angeles and San Diego metropolitan areas receiving Colorado River water. Estimated costs of using water of a given salinity concentration, predicted future average salinity concentrations and predicted future water ratio of use were utilized to estimate direct detriments. Detriment curves were prepared for 1960, 1980, 2010 conditions of water use and the salinity range expected during that time period. A detailed discussion of analytical techniques employed and a breakdown of the component costs are contained in Appendix B.

Determination of Penalty Costs--Differences in direct detriments associated with the use of water with different salinity concentrations are known as direct penalty costs. These penalty costs represent the marginal costs of using a degraded water supply.

The major emphasis of the economic studies conducted by the Project has been directed toward the determination of penalty costs as a means of assessing the economic impact of future increases in salinity concentrations. The results of Project economic studies in terms of penalty costs are presented in Appendix B. The analytical techniques employed to evaluate direct detriments (indirect penalty costs) utilize direct penalty costs as basic input. A determination of direct penalty costs is thus an interim step in the determination of total salinity detriments.

The relationship between direct detriments and direct penalty costs can be illustrated by the following example: Direct detriment curves for 1960, 1980, and 2010 conditions of water use are shown schematically in Figure 4. The direct detriments associated with use of water supplies with salinity concentrations of 700 mg/l and 900 mg/l in 1980 are shown by points "A" and "B" respectively. The difference between these detriments is a direct penalty cost for 1980 conditions associated with an increase in salinity levels from 700 to 900 mg/l.

To facilitate the determination of direct penalty costs, the water use and economic conditions existing in 1960 were selected as base conditions. For other time periods, increases in direct detriments resulting from increases in salinity concentrations above 1960 levels (697 mg/l at Hoover Dam) were calculated and designated as direct penalty costs. Direct penalty costs were determined separately for the Lower Colorado River subbasin and the southern California water service area.

Determination of Indirect Detriments--Input-Output analyses of the Lower Colorado River Basin and southern California economies were utilized as the basis for determination of indirect detriments or penalty costs. The analytical techniques utilized are discussed in Appendix B. Indirect detriments were determined separately for the Lower Colorado River subbasin, the Gila River subbasin and the southern California water service area. The combined totals of predicted direct and indirect penalty costs for the three areas for the

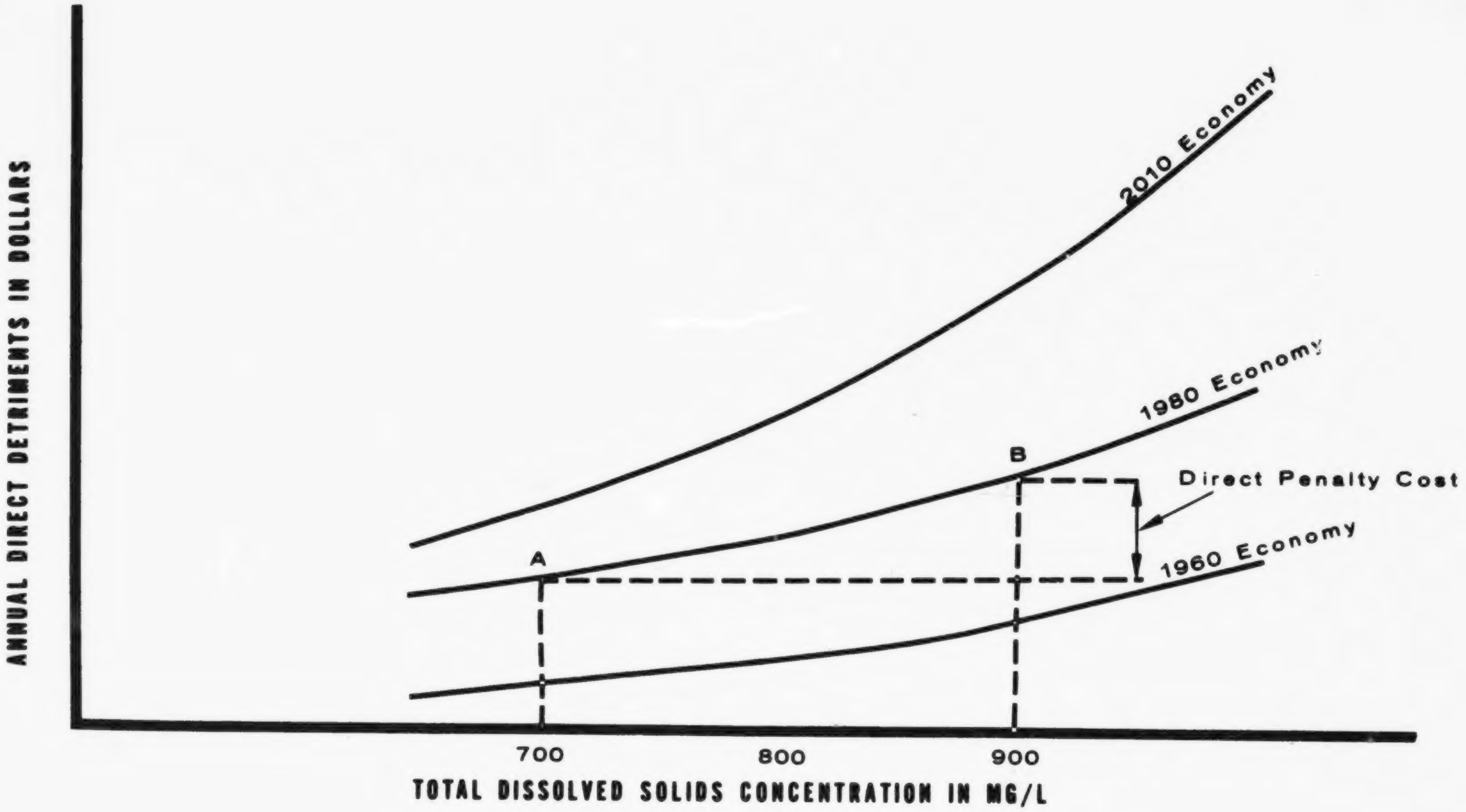

Figure 4. Illustration of Penalty Cost Evaluation

years 1980 and 2010 are summarized in Table 4. These costs are in terms of 1960 dollars.

A graphical summary of penalty costs is shown in Figure 5. It should be noted that penalty costs are related to salinity concentrations at Hoover Dam. Salinity concentrations at points of water use in the Lower Basin and Southern California can be directly related to salinity levels at Hoover Dam. Modifications of water volumes or salt loads in the drainage area of Lake Mead directly affect the salinity of Hoover Dam releases. Thus, the salinity concentration at Hoover Dam was selected as a convenient index of changes in Basin salinity levels.

Determination of Total Detriments.--To facilitate the evaluation of the economic feasibility of various salinity control measures, it was desirable to develop a series of detriment curves representing total costs to the economy of using a water supply with salinity concentrations at Hoover Dam varying from 600 to 1,000 mg/l and variations in the economy anticipated between 1970 and 2010 at 10-year intervals. Direct detriment curves developed for the evaluation of penalty costs discussed in the previous section provided the basis for development of the desired curves. These detriments has been computed for 1960, 1980, and 2010 conditions of water use and economic development and for salinity concentrations of 697, 876, and 990 mg/l. These nine points were utilized to develop detriment curves for 1960, 1980 and 2010. Straight-line interpolation was

Table 4. Direct and Indirect Penalty Costs Lower Colorado River Basin and Southern California Water Service Area

Type of Penalty Costs	Penalty Costs 1980 ($1,000 Annually)*	2010
Agricultural		
Direct	5,713	12,741
Indirect	3,212	8,557
Total	8,925	21,298
Industrial		
Direct	163	513
Indirect	7	20
Total	170	533
Municipal		
Direct	1,622	3,018
Indirect	318	546
Total	1,940	3,564
Total Direct	7,498	16,272
Total Indirect	3,537	9,123
TOTAL	11,035	25,395

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* 1960 Dollars

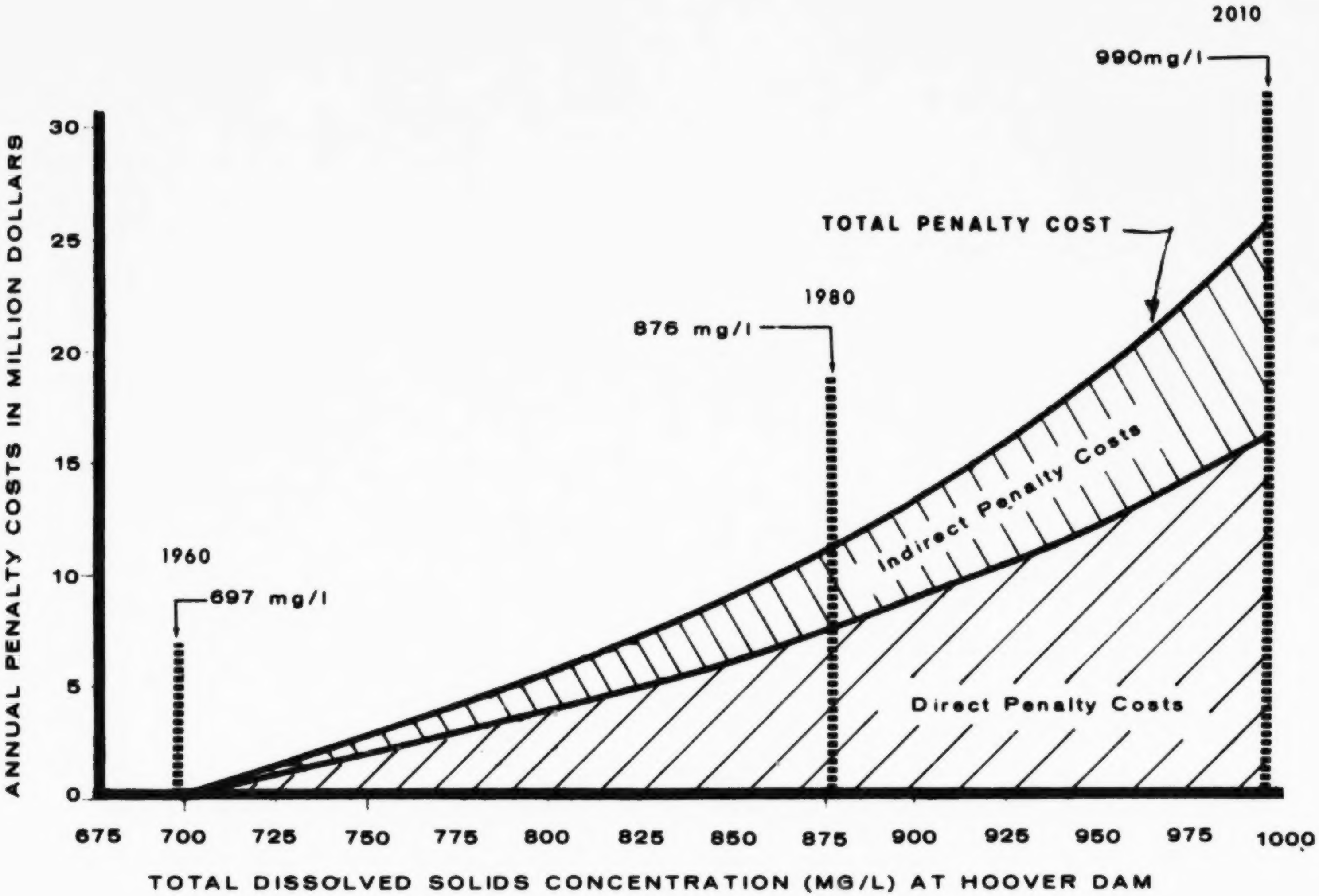

Figure 5. Direct & Indirect Penalty Costs Lower Colorado River Basin & California Water Service Area

utilized to develop curves for 1970, 1990, and 2000. The salinity range of the curves was then extended to the desired limits by extrapolation of indicated trends.

Direct penalty costs were computed at 10-year intervals from the newly developed curves using 1960 conditions of water use for base conditions. Indirect penalty costs were then derived from the direct penalty costs utilizing the assumptions that the ratios of indirect to direct costs computed from Table 4 for 1980 and 2010 conditions would hold over the full salinity range and that similar ratios for other years could be interpolated. The utilization of these assumptions eliminated substantial input-output analysis.

The summation of the indirect penalty costs derived in this manner and direct detriment costs resulted in the development of total detriment curves expressed in Terms of 1960 dollars. To update these curves to present conditions, they were adjusted for changes in the value of the dollar from 1960 to 1970.

One popular index of the average change in the purchasing power of the dollar is the Consumer Price Index. This index increased from 103 in 1960 to 131 in early 1970. (16) This change would indicate that a 1960 dollar was equivalent to 1.27 1970 dollars. The detriment curves were adjusted upward on this basis. The use of a single index was considered adequate for this adjustment since other appropriate indexes, such as the agricultural price index, which could be applied have increased in essentially the same proportions as the CPI.

The final total detriment curves which represent the total impact on the economy of using saline waters in terms of 1970 dollars are shown in Figure 6. These detriments curves can be utilized to determine the salinity control benefits that would accrue to a specific salinity control project. Such benefits are the differences in detriments associated with salinity concentrations which would occur with or without implementation of the control project.

Sensitivity Analysis.--To provide a basis for evaluating future salinity penalty costs, a detailed evaluation was made of present and future salinity levels at various points throughout the basin. The details of this evaluation are discussed in Appendix B. Such factors as the period of hydrological record and the rate of increase in consumptive use resulting from water resource development may produce significant variations in projections of future salinity levels. These variations in turn may affect predictions of the future economic impact of salinity increases. The sensitivity of salinity and economic projections to variations in mean annual virgin streamflow and future depletions of steamflow are discussed in this section.

The basic salinity projections utilized for the detailed economic analysis were based on the 1942-1961 period of record adjusted for 1960 conditions of water use. The mean annual virgin flow at Lees Ferry, Arizona, for this period was estimated to be 13.8 million acre-feet. (9) There is a probability of about 0.78 that this value will be exceeded by any 20-year mean virgin

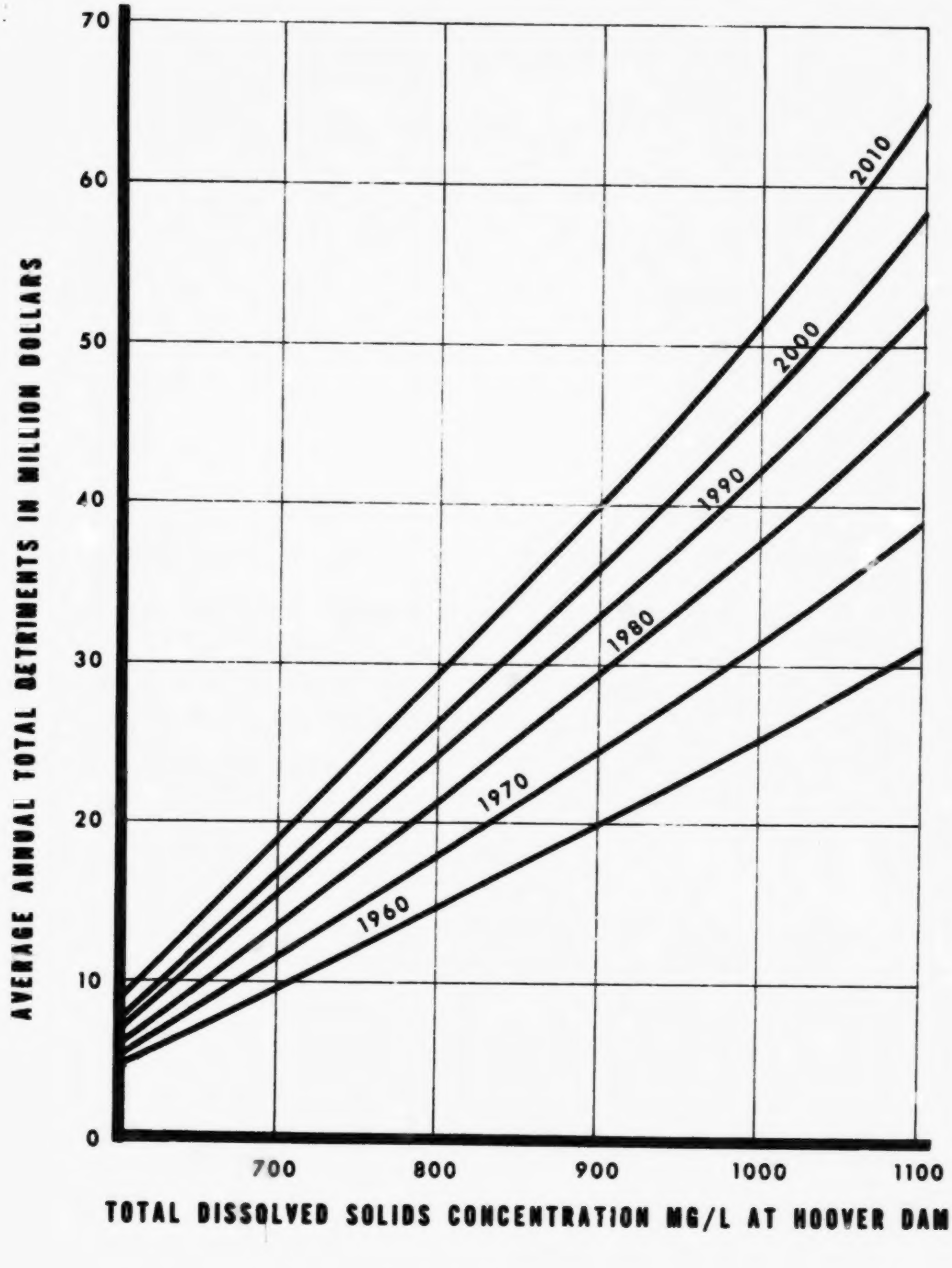

Figure 6. Salinity Detriments

flow.(17) The rationale behind selection of this period of record is summarized in Appendix B and will not be discussed here.

To test the sensitivity of salinity projections to variations in the base flow utilized in the analysis, three additional base flows with different probabilities of occurrence were evaluated. The flows evaluated were a 50-year mean flow with a probability of being exceeded of 0.50 and two 20-year mean flows with probabilities of being exceeded in 20-year period of 0.125 and 0.875.(17) These latter two flows are the upper and lower limits of a probable 75 percent of all 20-year mean flows. The virgin flow volumes for the four base flows evaluated are listed in Table 5. Salinity projections were made on the basis of identical present and future depletions of these virgin flows for all flow levels. Salt loads for the three additional base flows were estimated by adjusting the 1942-1961 mean salt load using the assumption that incremental changes in virgin flow would have a salinity concentration of 300 mg/l. This salinity concentration was selected from comparisons of salinity concentrations vs runoff relationship for low and high flow years.(9)

Table 5. Range of Virgin Flows at Lees Ferry

Designation	Virgin Flow (Million Acre-Feet)	Probability of Being Exceeded in a 20-year Period
Upper Limit	16.8	0.125
Mean Flow	15.4	0.500
Base Flow	13.8	0.780
Lower Limit	13.2	0.875

Projections of present and future salinity concentrations for the four base flows evaluated are shown in Figure 7. Projected

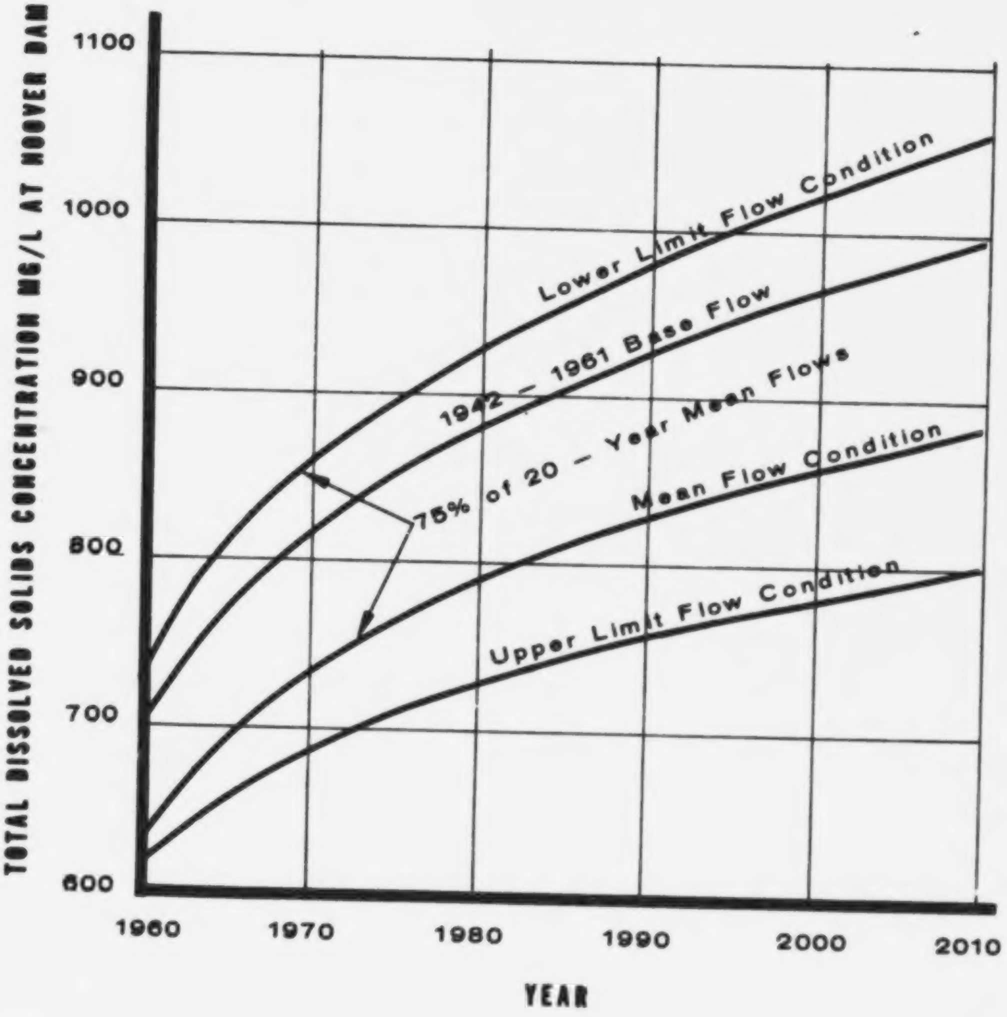

Figure 7. Sensitivity of Salinity Projections to Base Flow Variations

increases in salinity concentrations between 1960 and 2010 range from 180 to 330 mg/l. The basic analysis base flow of 13.8 million acre-feet predicted an increase of 293 mg/l.

The detriment curves in Figure 6 and the salinity projections in Figure 7 were utilized to formulate projections of future increases in salinity detriments. These projections are shown in Figure 8. Predicted increases in total annual detriments (total penalty costs) between 1960 and 2010 range from $23 million to $46 million. The basic analysis predicted an increase of $40 million. This wide range of predicted penalty costs indicates that the economic analysis is highly sensitive to variations in mean streamflow. However, the base analysis deviated only 20 percent from predicted changes under mean flow conditions. Selection of a more critical low-flow condition, a common practice in water pollution analysis, did not substantially alter the determination of penalty costs.

Considerable differences of opinion exist over the rate at which Upper Basin water resource development and increased depletion of streamflow will proceed. For the basic analysis, a depletion schedule based primarily on 1966 Bureau of Reclamation estimates was used.(18) Some authorities predict that development will proceed at a more rapid rate than the schedule selected. Actual development to date has been slightly slower due to fiscal constraints. If such constraints continue they could further delay future development. Three additional depletion schedules were evaluated to test the sensitivity of salinity and penalty cost projections to variations in depletions.

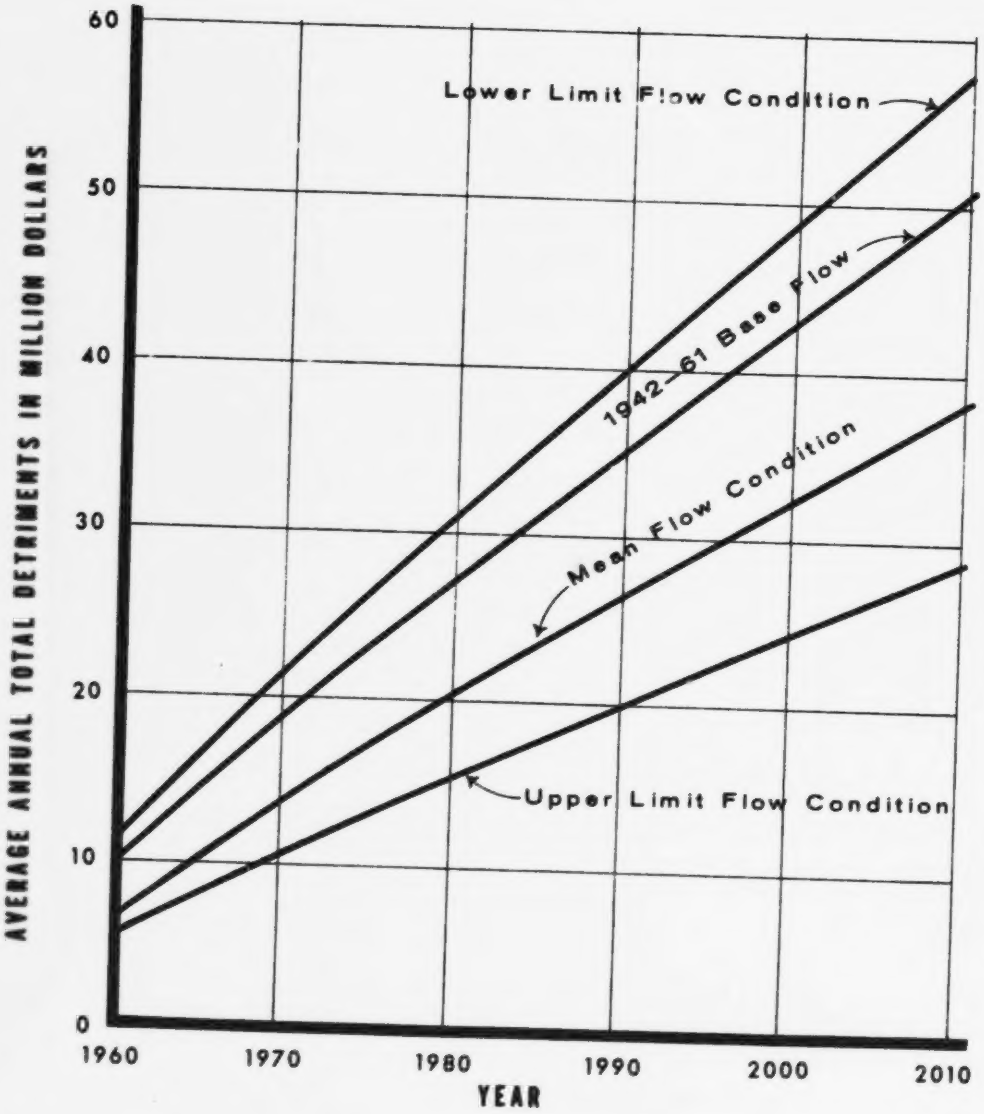

Figure 8. Sensitivity of Detriment Projections to Base Flow Variations

An accelerated schedule was utilized to evaluate optimistic projections, a mean schedule was utilized to represent, present trends and a reduced schedule was utilized to reflect possible future delays. Figure 9 and 10 present the salinity and detriment projections resulting from this sensitivity analysis. The smaller range between upper and lower limits on these projections would indicate a lower degree of sensitivity than that exhibited by variations in base flow. The convergence of the accelerated depletion and base analysis curves is the result of constraints imposed by the Colorado River Compact on maximum depletions.

Salinity Management Costs

If salinity concentrations are reduced by the implementation of control measures, certain costs will be incurred. These costs are known as salinity management costs and are the second major component of total salinity costs. The form and magnitude of salinity management costs are dependent upon a number of factors including the control measures utilized, the degree of salinity control achieved, etc. In a previous section on alternative salinity control management programs, the phased implementation of a salt load reduction program was selected as the least cost alternative for achieving basinwide management of salinity. The probable costs and effects of this least cost alternative program were evaluated as a means of estimating salinity management costs and are discussed in their section.

Available information on the costs and effects of salinity control measures from the latest technical investigation, research

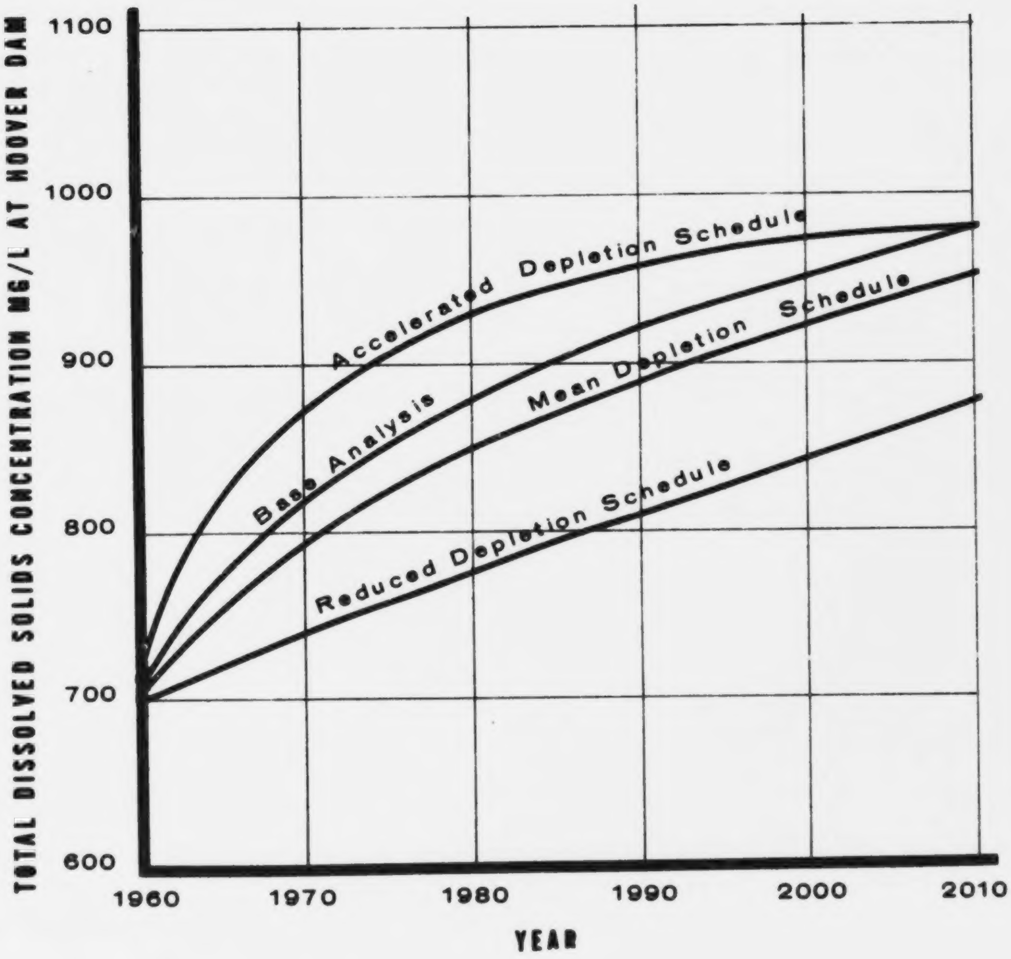

Figure 9. Sensitivity of Salinity Projections to Depletion Schedule Variations

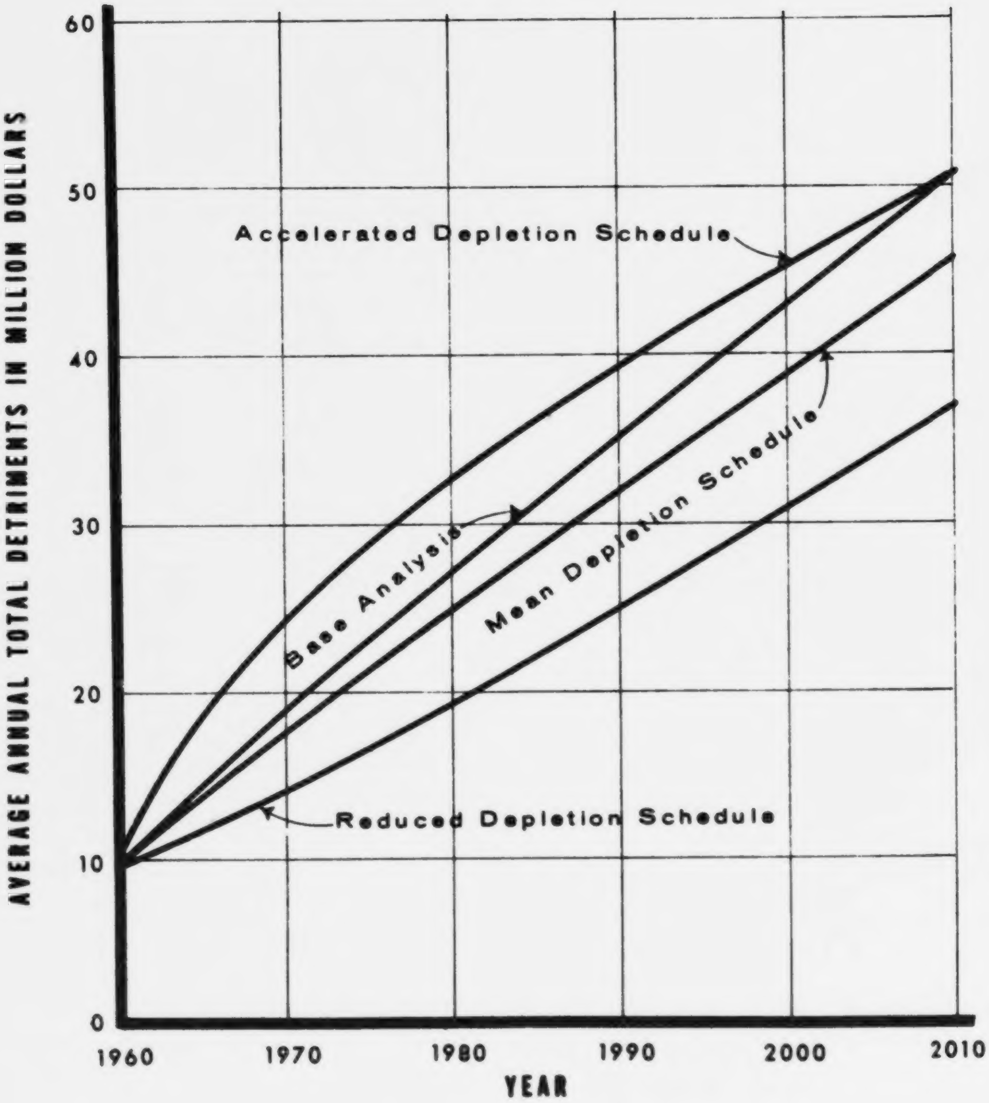

Figure 10. Sensitivity of Detriment Projections to Depletion Schedule Variations

and demnonstration activities was not sufficient to permit development of detailed estimates of project costs and salt-load reductions. To overcome this deficiency, Bayesian statistical decision theory, a statistical technique applicable to cases involving limited basic data, was utilized to provide estimates of the expected value of costs and salt load reduction for each individual project or irrigated area included in the selected program. Bayesian techniques differ from classical statistical techniques in that mean or expected values of a parameter may be derived by subjective assignment of probabilities of occurrence to each data point rather than by application of computational formulas to all data points in the classical manner. In cases of limited data, the appropriate application of Bayesian techniques may result in better estimates of the expected value of a parameter for a specific case than could be derived by averaging available data or extrapolating from one case to another.

The approach used to estimate costs and salt load reductions for each type of control measure differed slightly. For irrigation improvements, the costs of various types of improvements are relatively well defined. Two areas of uncertainty arise, however. The magnitude of improvements which a given irrigated area can economically support has not been evaluated. It was therefore necessary to estimate the range of improvements possible and the probability of each level of improvement occurring. Also, the average salt contribution of a given area was known but the extent to which this salt load could be reduced by specific improvements has not yet been defined with certainty. Estimates of the possible range of salt load reductions and the probability of occurrence of each level of reduction were made based on recent research results and observed variations in annual salt contributions of the areas evaluated. The estimates of probable salt load reductions were also keyed to levels of improvement. A low level of salt load reduction was assigned to minimum improvements, a higher reduction to more extensive improvements, etc. In this manner, an upper and lower limit and an expected (mean) value of both salt load reductions and annual costs were derived for each irrigated area.

For the five salt load reduction projects formulated for control of natural sources, the magnitude of the salt loads to be controlled are relatively well defined. Since structural designs or geological site data were not available, however, detailed cost estimates could not be prepared. Thus, for these control projects, probable construction costs were the primary area of uncertainty. Possible ranges of costs were estimated and Bayesian techniques utilized as for the irrigation improvements to estimate upper and lower limits and expected values of salt load reductions and average annual costs.

The estimated expected values of both average annual costs and salt load reductions for the selected salt load reduction program are presented in Table 6. This table is an expansion of

Table 6. Salinity Management Project Date

	PROJECT DESCRIPTION		AVERAGE ANNUAL COSTS		EFFECTS AT HOOVER DAM				
							TDS Reduction in mg/l		
No.	Location	Features	Total Proj. Cost ($1000)	Salinity Control Costs ($1000)	Flow Change (1000 AF/Yr)	Salt Load Reduction (1000 T/Yr)	1980	2010	Cost Index (S/T)
1	Paradox Valley, Colorado	Stream Diversion	700	700	0	180	15	16	3.89
2	Grand Valley, Colorado	Irrigation Improvement	3,140	1,570	38	312	29	33	5.04
3	Lower Stem Gunnison River, Colorado	Irrigation Improvement	3,600	1,800	45	334	32	35	5.40
4	Price River, Utah	Irrigation Improvement	1,000	500	13	89	9	9	5.65
5	Las Vegas Wash, Nevada	Export & Evaporation	600	600	- 10	100	7	8	6.00
6	Uncompahgre River, Colo.	Irrigation Improvement	4,000	2,000	50	320	31	35	6.25
7	Big Sandy Creek, Wyoming	Irrigation Improvement	490	245	7	39	4	4	6.28
8	La Verkin Springs, Utah	Impoundment & Evap.	600	600	- 7	80	6	6	7.50
9	Roaring Fork River, Colo.	Irrigation Improvement	880	440	13	52	6	6	8.47
10	Upper Stem Colorado River, Colorado	Irrigation Improvement	1,420	710	20	80	9	9	8.88
11	Henry's Fork River, Utah	Irrigation Improvement	710	355	- 10	40	4	5	8.88
12	Dirty Devil River, Utah	Irrigation Improvement	710	355	10	40	4	5	8.88
13	Duchesne River, Utah	Irrigation Improvement	5,660	2,830	65	273	29	32	10.37
14	San Rafael River, Utah	Irrigation Improvement	1,360	680	18	65	7	8	10.48
15	Ashley Creek, Utah	Irrigation Improvement	830	415	10	36	4	4	11.55
16	Glenwood Springs, Colo.	Desalination	5,000	5000	- 5	370	30	33	13.50
17	Blue Springs, Arizona	Export & Desalination	16,000	16,000	- 150	500	27	27	32.00
	Totals		46,700	34,800	127	2,910	253	275	--

Table 2 presented in a previous section of alternative salinity management programs. The physical features of the seventeen component projects are discussed in that section.

Two costs, total project costs and salinity control costs, are shown for each project in Table 6. These costs are in the form of average annual costs which include amortized construction, operation and maintenance costs. Total project costs, as the name indicates, consist of the total costs required to build, operate and maintain the specific project. Salinity control costs represent the portion of total costs allocated to salinity control. For the five single-purpose salt load reduction projects, all cost were allocated to salinity control. The irrigation improvements will produce other benefits of significant economic value in addition to salinity control benefits. Estimates of benefits produced by similar improvements which have been made by other agencies would indiciate that these benefits are of about the same economic value as salinity control benefits. Thus, allocation of costs in proportion to benefits resulted in assignment of onehalf of total irrigation improvement costs to salinity control.

Except for the Paradox Valley project, the various salinity control projects will produce a change in consumptive use of water. The entire flow from LaVerkin Springs and from Las Vegas Wash would be evaporated. For Glenwood Springs, the majority of the springs' discharge would be returned to the river system but some consumptive use would result from disposal of brine. Control of Blue Springs would remove this discharge from the Colorado River system. The majority of the flow diverted would be available for consumptive use in central Arizona. The various irrigation improvements would result in water conservation. Reductions in consumptive use by phreatophytes, evaporation, etc. were estimated to average about one-half acre foot per irrigated acre when an entire irrigated area is improved. The estimated changes in flow at Hoover Dam for specific projects are shown in Table 6.

Utilizing the estimated changes in consumptive use and expected values of salt load reductions, the estimated reductions in average salinity concentrations at Hoover Dam were computed. Salinity reductions for each project for the years 1980 and 2010 are shown in Table 6. The effectiveness of a given salinity management project in reducing average salinity concentrations at Hoover Dam is dependent upon the volume and salinity of the average streamflow at Hoover Dam. Since future water resource development will reduce streamflow at Hoover Dam, a given salt-load reduction will produce a greater reduction in salinity concentrations in the future than a present. This fact is reflected in the differences between potential salinity reductions for 1980 and 2010.

The final parameter shown in Table 6 for each project is a cost index. This index is the ratio of average annual salinity control costs to annual salt load reductions. The index is an indicator of the cost effectiveness of each project and was utilized to rank the projects in an order of increasing unit costs.

Utilizing the cost and salinity reduction data from Table 6, it was possible to construct a graph relating cumulative salinity management costs to cumulative reductions in salinity concentrations. Salinity management cost curves of this type for 1960, 1980, and 2010 conditions of water use are shown in Figure 11. By ranking projects in order of increasing unit costs, a curve that is concave upward results. The slope of the curve is related to the unit costs of salinity reduction.

In view of the elements of uncertainty that entered into the determination of the costs and salt load reductions of individual projects, it was desirable to test the sensitivity of the salinity management cost curve to variations in the costs and effects of individual project. This test was accomplished by plotting two additional salinity management cost curves utilizing the estimated upper and lower limits of costs and salt load reductions for each project. A comparison of the three curves for 1980 conditions of water use is shown in Figure 12. Although the range of possible costs and effects for a given project is large, the costs of achieving a given level of salinity reduction fall within a reasonable range for moderate levels of salinity control. This would indicate that cumulative salinity management costs have a relatively low sensitivity to errors in estimates for individual projects.

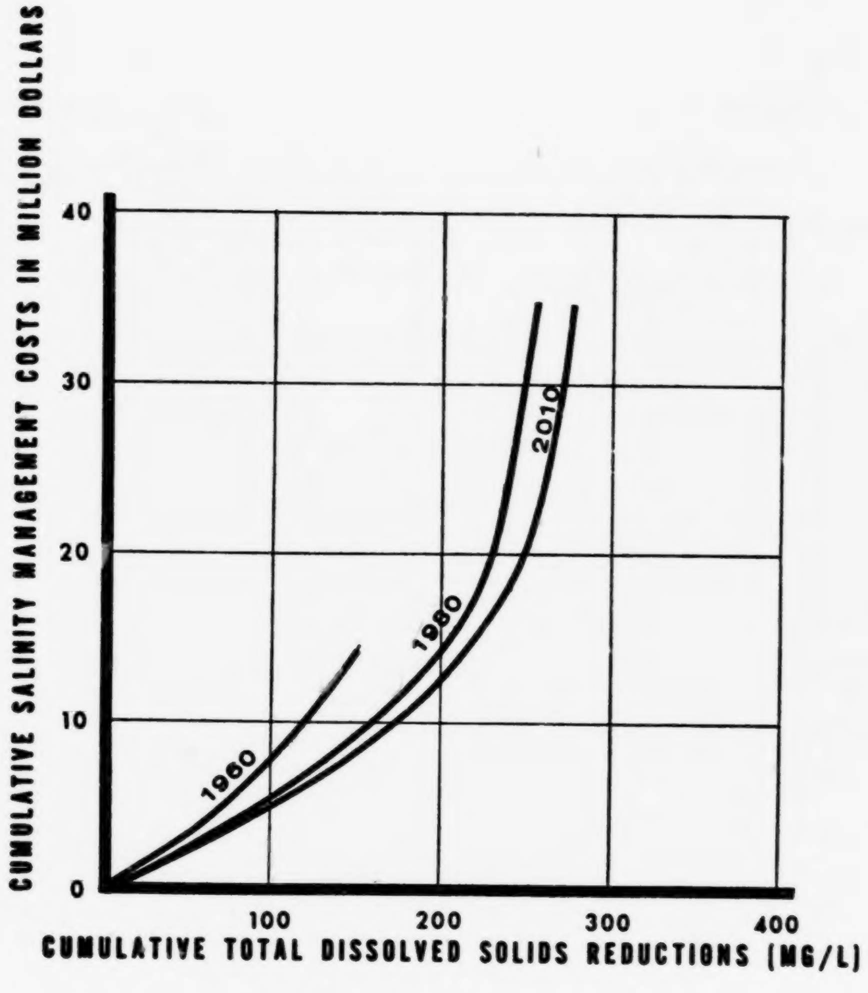

Figure 11. Salinity Management Costs

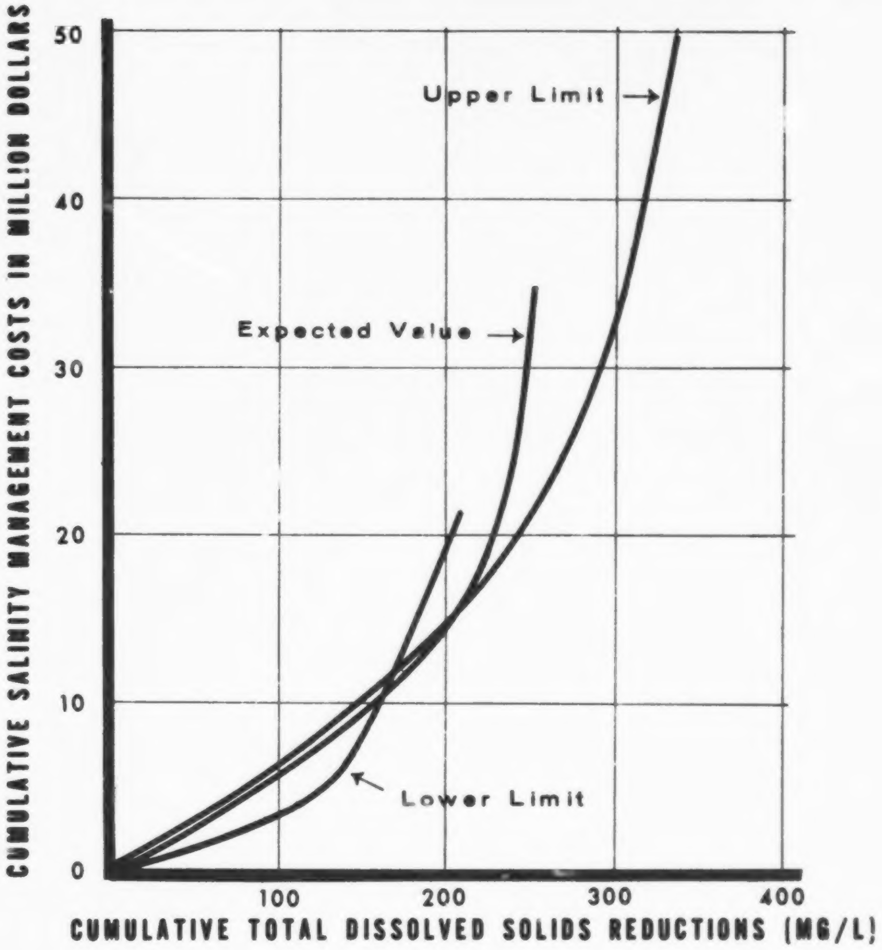

Figure 12. Salinity Management Cost Variations

Total Economic Impact

The total economic impact of salinity (total salinity costs) is the sum of salinity detriments plus salinity management costs. For a given salinity concentration and point in time, there are certain detriments associated with the use of water of that salinity and certain salinity management costs incurred in maintaining that salinity level. The sum of these two component costs is thus the total economic impact of salinity for the given time and salinity conditions.

Generalized total salinity cost curves can be developed by the proper manipulation and addition of the detriment curves presented in Figure 6 and the salinity management cost curve of Figure 11. An example of the determination of total salinity costs for 1980 conditions is shown in Figure 13. The 1980 detriment curve is identical to the one shown in Figure 6. Salinity concentrations at Hoover Dam are predicted to average 876 mg/l in 1980. This salinity level than becomes the origin of the salinity management cost curves. As salinity reductions increase, salinity concentrations decrease. The salinity management cost curve must therefore be plotted in the reverse direction of Figure 11 as shown on Figure 13. These two curves can then be summed vertically to yield the total cost curve.

In a similar manner, total cost curves were obtained for each decade from 1970 to 2010. These curves are shown in Figure 14. The component salinity detriment and salinity management

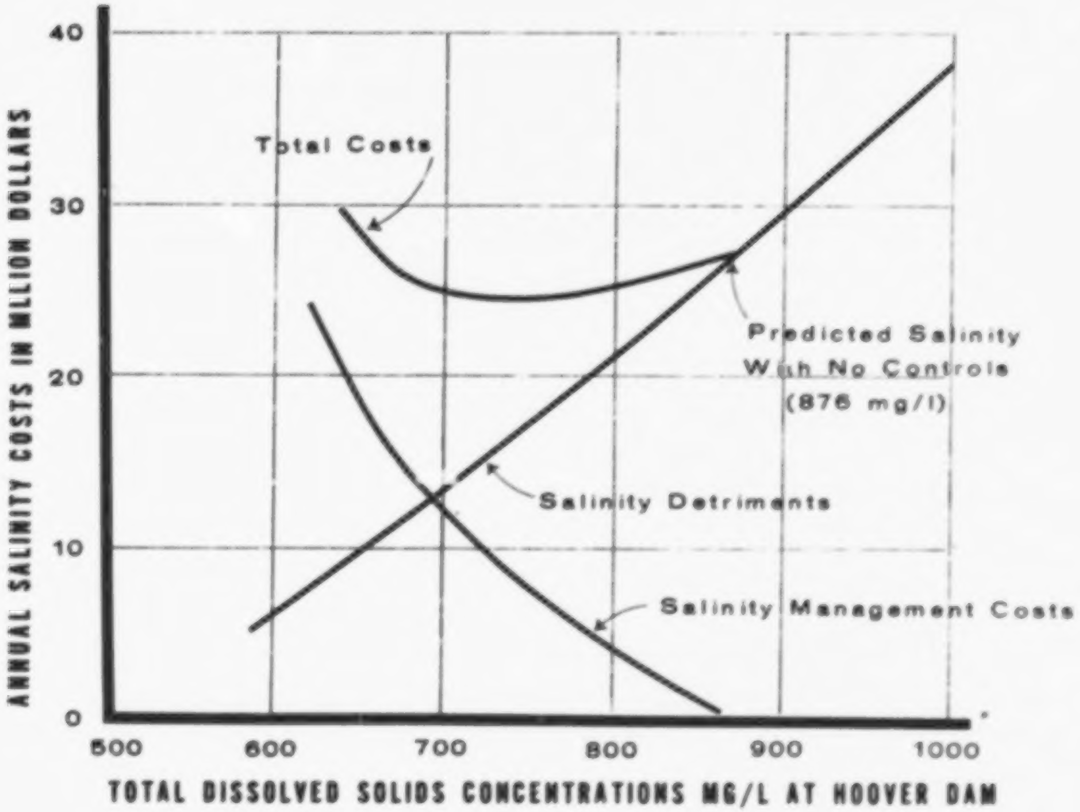

Figure 13. Determination of Total Salinity Costs (1980 Conditions)

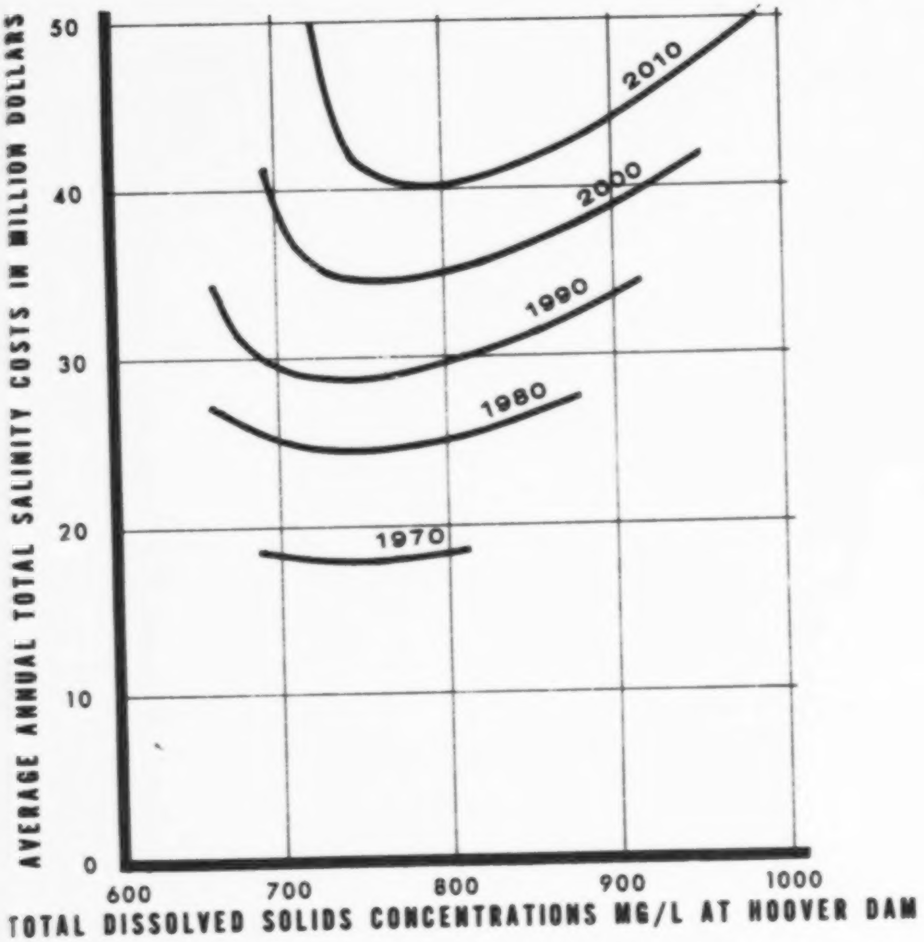

Figure 14. Total Salinity Costs

cost curves were not shown in this figure to avoid cluttering the drawing but may be obtained from Figure 6 and 11. It should be noted that the full lengths of the total cost curves are not shown in Figure 14 as the left end of each curve was truncated at a total cost equal to that at the right end of the curve. The segments of the curve shown were utilized for the evaluation alternative salinity management objectives discussed in the following section.

In view of the range of salinity management costs exhibited by the sensitivity analysis shown pictorially in Figure 12, it was desirable to check the sensitivity of the total cost curves to this range of management costs. The range of 1980 total costs obtained by using the three 1980 salinity management curves is shown in Figure 15. For 1980 conditions, total costs deviated only ± 10 percent from the expected value within the range of practical salinity management (700 to 876 mg/l). Salinity concentrations corresponding to minium total cost points varied less than 30 mg/l from the expected value. Similar results were obtained for other time periods. Total costs thus appear to be relatively insensitive to errors in deriving salinity management costs within the range of practical salinity management.

ECONOMIC AND WATER QUALITY EFFECTS

Salinity controls could be implemented to meet a variety of salinity management objectives which include both water quality and economic objectives. Since salinity levels and

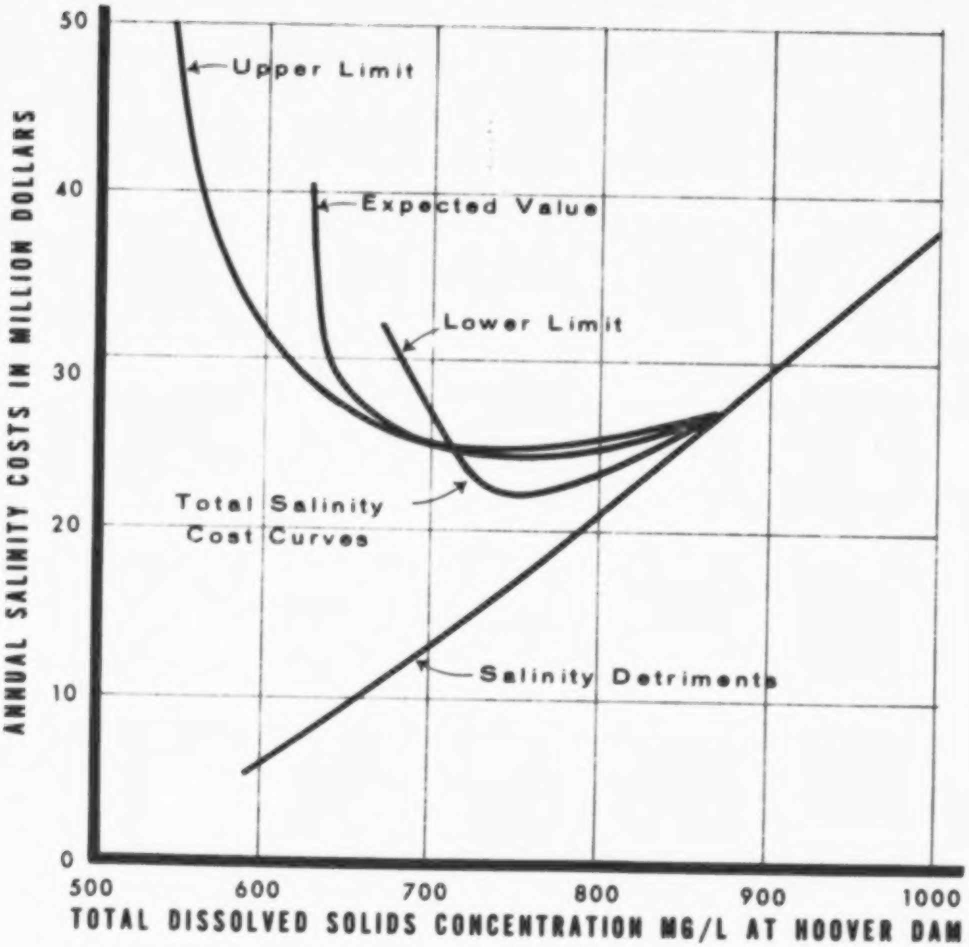

Figure 15. Total Salinity Cost Sensitivity Analysis
(1980 Conditions)

total salinity costs are interrelated, the selection of a water quality objective will result in the indirect selection of associated economic effects; conversely, the selection of an economic objective will result in the selection of associated salinity levels. A knowledge of the interrelationships between economic and water quality effects is thus useful in the rational selection of salinity management objectives.

By utilizing the total cost functions shown in Figure 7, the economic and water quality effects associated with three salinity management objectives were determined. The objectives evaluated were: (1) Maintain salinity at a level which minimize its total economic impact and achieve economic efficiency (minimum cost objective); (2) Maintain salinity concentrations at some specified level (constant salinity objective); and (3) Maintain salinity at some low level for which the total economic impact would be equal to the economic impact that would be produced if no action were taken at all (equal cost objective) A comparison of the economic and water quality effects associated with these three objectives, in the form of variations in salinity costs with time, are shown in Figure 16 for 1980 conditions of water use. The economic and water quality effects associated with allowing unlimited water resource development in the absence of salinity control works (no control approach) and associated with the limited development approach are shown in Figure 16.

In Figure 16, the right end of the total cost curve

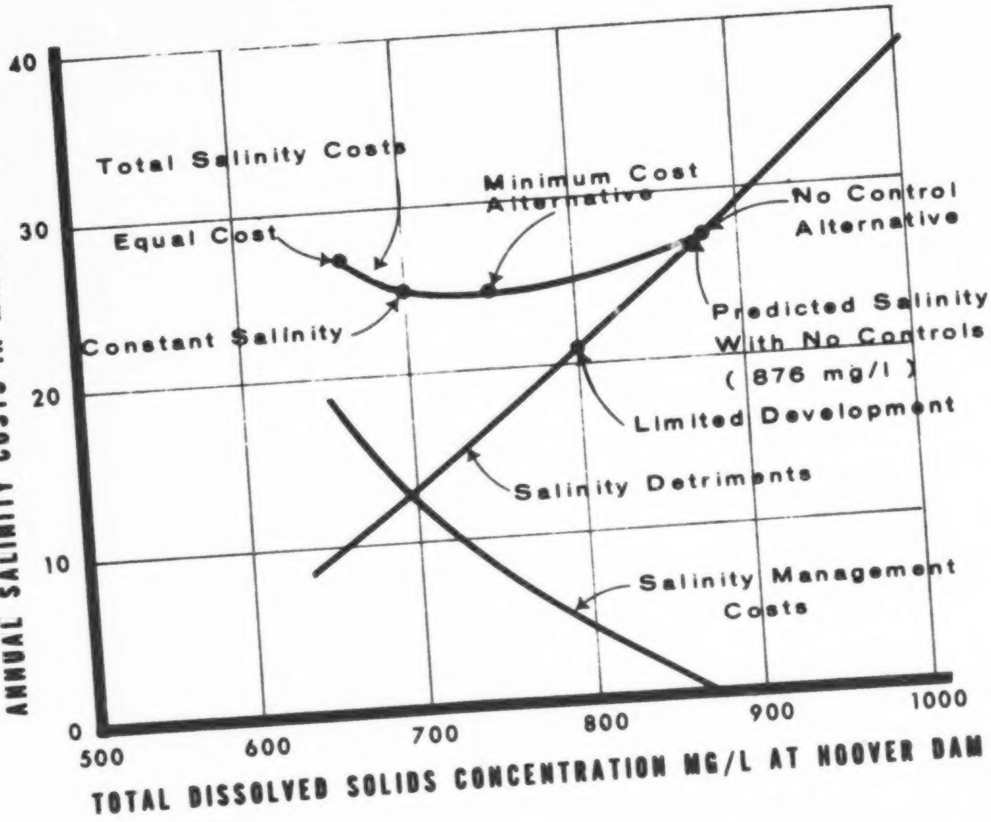

Figure 16. Comparison of Alternative Objectives (1980 Conditions)

corresponds to the projected salinity level at Hoover Dam if no controls are implemented (876 mg/l) and thus determines the total cost associated with the no control alternative. The salinity level associated with limited development intersects the salinity detriment curve to show that costs associated with the limited development alternative would be about $21 million annually and are obtained from salinity detriments alone. It should be noted that there are no control costs associated with the $21 million dollar total costs. In a very real sense, however, there are additional costs associated with this alternative in the form of benefits foregone. In fact, from Figure 16 one can observe that if benefits foregone exceed $4 million annually ($25 million - $21 million), this alternate would have total costs exceeding the total costs for alternates which include salinity control costs while allowing development to proceed beyond 1980.

All points on the total cost curve to the left of the no control point correspond to come level of salinity control. At the low point in the total cost curve, the total costs of salinity are at a minimum for the given conditions of water use and unconstrained development. Implementing salinity controls to reduce average salinity concentrations to this level would achieve the minimum cost objective.

At the left end of the total cost curve, total salinity costs are equal to total costs associated with the no control alternative. The left end of the curve thus corresponds to the equal cost alternative.

Total costs associated with a constant salinity objective are dependent upon the target salinity level selected and are determined by finding the intersection of the target level with the total cost curve. For this evaluation, a target salinity concentration of 700 mg/l was selected which corresponds closely to the average salinity level for 1960 conditions of water use.

The relative effects of the five alternatives were determined for other target years from Figure 14 in the same manner as shown by Figure 16. The economic effects associated with the five alternatives, in the form of variations in salinity costs with time, are shown in Figure 17.

Total salinity costs would be minimized by the limited development alternative but one must recognize the absence of cost associated with benefits foregone. If unrestricted water resource development is permitted, implementing salinity controls to achieve the minimim cost objective would minimize total salinity costs. The no control and equal cost alternatives produce the identical highest average costs and most rapid increase with time of all the alternatives evaluated. Total costs associated with a constant salinity objective will fall somewhere between the extremes established by the other alternatives with the exact cost dependent upon the target salinity level. For a target level of 700 mg/l, total costs approximate minimum costs until 1990, then increase rapidly, eventually exceeding the no control costs. Beyond the year 2000, the rapidly increasing costs reduce the practicality of maintaining this salinity level. Selection

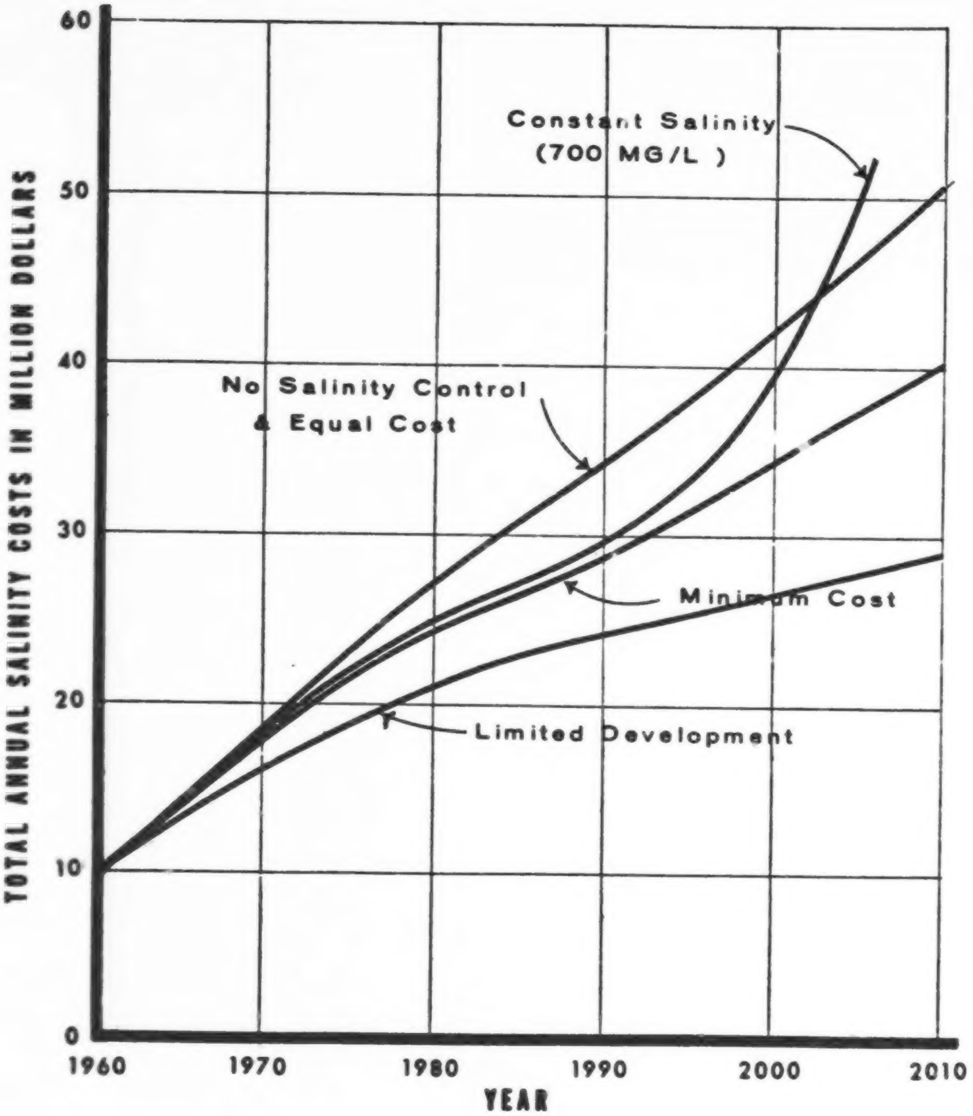

Figure 17. Salinity Costs vs Time

of a higher target salinity concentration for the years 2000 and 2010 would reduce the total cost of this alternative.

One important observation can be made from Figure 17. Regardless of the alternative selected, the future economic impact of salinity will be great. Although implementing salinity controls will result in the availability of better quality water for various uses and some of the economic impact will be shifted from salinity detriments to salinity management costs, the total economic impact of salinity will not be substantially reduced. As a minimum, average annual total salinity costs will increase threefold between 1960 and 2010. Selection of the limited development alternative would reduce total annual costs by only about 40 percent below the no control alternative in the year 2010.

Variations with time of the predicted salinity levels associated with the five alternatives evaluated are shown in Figure 18. With no controls implemented, average annual salinity concentrations at Hoover Dam are predicted to increase between 1960 and 2010 by about 42 percent or 293 mg/l. Selection of any of the other alternatives evaluated would substantially reduce future salinity concentrations below the no control levels. Except for the limited development alternative, these reductions would result in the maintenance of average salinity concentrations at or below present (1970) levels for more than 25 years. Resulting water quality therefore would be consistent with non-degradation provisions of the water quality standards adopted

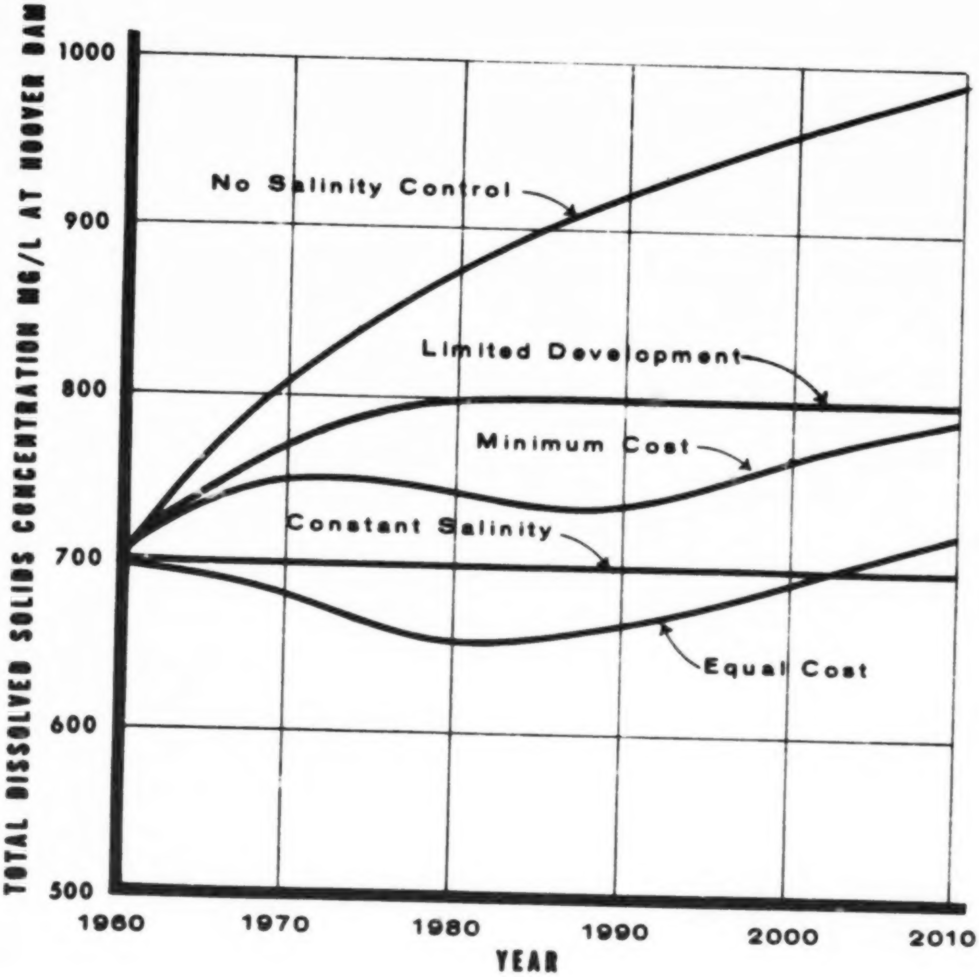

Figure 18. Salinity Concentration vs Time

Table 7 Comparison of Salinity Cost Distribution

Alternative Objective	Date	Salinity Detriments ($1,000/Yr)	Salinity Management Costs			Total Salinity Costs ($1,000/Yr)
			Salt Load Reduction Projects ($1,000/Yr)	Salinity Control Costs ($1,000/Yr)	Total Salinity Management Costs ($1,000/Yr)	
No Control	1980	27,700	0	0	0	27,700
	2010	50,500	0	0	0	50,500
Limited Development	1980	21,000	0	0	0	21,000
	2010	29,000	0	0	0	29,000
Minimum Cost	1980	17,000	1,300	5,900	7,200	24,200
	2010	28,500	1,900	10,800	12,700	41,200
Constant Salinity (700 mg/l)	1980	13,500	1,900	10,000	11,900	25,300
	2010	19,000	25,000	13,500	38,500	57,500
Equal Cost	1980	9,200	6,900	11,600	18,500	27,700
	2010	21,000	17,600	11,900	29,500	50,500

by the seven Basin States. The limited development alternative would result in slight increases in average salinity concentrations.

COST DISTRIBUTIONS AND EQUITY CONSIDERATIONS

Although the total economic impact of salinity associated with each of the alternatives evaluated varies over a limited range, the distribution of salinity costs related to each alternative differs greatly. Distribution of costs may therefore be an important factor in the selection of alternatives. Associated with cost distributions are various equity considerations. These, too, influence the selection of alternatives. Salinity cost distributions for the five alternatives evaluated for both 1980 and 2010 conditions of water use are compared in Table 7. A further breakdown of salinity management costs, by individual projects, is shown in Table 6.

The no control and equal cost alternatives produced the extremes in the range of cost distributions evaluated. Total costs for these two alternatives, by definition, are equal but the distributions of costs are vastly different. For the no control alternative, all costs are in the form of detriments. For the equal cost alternative, however, salinity detriments are reduced by an average of 60 percent. This cost reduction is offset by a corresponding increase in salinity management costs.

The extremes in the range of cost distribution point out the basis for equity considerations which may enter into the selection of management objectives. If the no control alternative is selected, all salinity costs would essentially be borne by water users and by the regional economy in the Lower Basin and southern California water service area. In contrast, selection of the equal cost alternative would redistribute a majority of the costs to investments in salinity control facilities in the drainage area upstream from Hoover Dam. Much of this investment would be for irrigation improvements in the Upper Basin, improvements that would produce substantial economic benefits in addition to salinity control benefits. The equity of these two extremes in cost distributions is vastly different.

Salinity detriments for the other three alternatives evaluated fall between the extremes established by the no control and equal cost alternatives. Salinity management costs are less than for the equal cost alternative. The equity of these cost distributions may also be an important factor in selection of the most desirable alternative. The cost distribution shown in Table 7 can be used to evaluate the relative costs and benefits of a given alternative. For example, a salinity control program designed to meet the minimum cost objective would have an estimated average annual cost of $7.2 million in 1980 and $12.7 million in 2010. The benefits associated with a given alternative would be the difference between salinity detriments expected if no controls are implemented and if the control program associated with that alternative is implemented. For the minimum cost alternative, average annual salinity control benefits would total $10.7 million in 1980 and $22.0 million in 2010.

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THE MINERAL QUALITY PROBLEM
IN THE COLORADO RIVER BASIN

APPENDIX D

COMMENTS ON DRAFT REPORT

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGIONS VIII AND IX

1971

THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency was established by Reorganization Plan No. 3 of 1970 and became operative on December 2, 1970. The EPA consolidates in one agency Federal control programs involving air and water pollution, solid waste management, pesticides, radiation and noise. This report was prepared over a period of eight years by water program components of EPA and their predecessor agencies -- the Federal Water Quality Administration, U.S. Department of Interior, April 1970 to December 1970; the Division of Water Supply and Pollution Control, U.S. Public Health Service, prior to October 1965. Throughout the report one or more of these agencies will be mentioned and should be considered as a part of a single agency -- in evolution.

PREFACE

The Colorado River Basin Water Quality Control Project was established as a result of recommendations made at the first session of a joint Federal-State "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and its Tributaries," held in January of 1960 under the authority of Section 8 of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.). This conference was called at the request of the States of Arizona, California, Colorado, Nevada, New Mexico, and Utah to consider all types of water pollution in the Colorado River Basin. The Project serves as the technical arm of the conference and provides the conferees with detailed information on water uses, the nature and extent of pollution problems and their effects on water users, and recommended measures for control of pollution in the Colorado River Basin.

The Project has carried out extensive field investigations along with detailed engineering and economic studies to accomplish the following objectives:

(1) Determine the location, magnitude, and causes of interstate pollution of the Colorado River and its tributaries.

(2) Determine and evaluate the nature and magnitude of the damages to water users caused by various types of pollution.

(3) Develop, evaluate, and recommend measures and programs for controlling or minimizing interstate water pollution problems.

In 1963, based upon recommendations of the conferees, the Project began detailed studies of the mineral quality problem in the Colorado River Basin. Mineral quality, commonly known as salinity, is a complex Basin-wide problem that is becoming increasingly important to users of Colorado River water. Due to the nature, extent, and impact of the salinity problem, the Project extended certain of its activities over the entire Colorado River Basin and the Southern California water service area.

The more significant findings and data from the Project's salinity studies and related pertinent information are summarized in the report entitled, "The Mineral Quality Problem in the Colorado River Basin." Detailed information pertaining to the methodology and findings of the Project's salinity studies are presented in three appendices to that report -- Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality," Appendix B, "Physical and Economic Impacts," and Appendix C, "Salinity Control and Management Aspects."

Copies of the draft report, including the three appendices, were distributed to state and Federal government agencies in April. Comments, received in response to that distribution, are included in this appendix. The comments are organized alphabetically by state. Within each state heading, comments from the appropriate Conferee are placed first, followed by comments from other state agencies. Comments from other recipients of the distribution conclude the appendix.

Due to minor editorial changes, page numbers in the draft report as referenced in various state comments may not always correspond to page numbers in the final report.

ARIZONA

Arizona State Department of Health

ARIZONA STATE OFFICE BUILDING
1624 WEST ADAMS STREET
PHOENIX, ARIZONA 85007

LOUIS C. KOSSUTH, M.D., M.P.H.
Commissioner of Health

REPLY TO:
ENVIRONMENTAL HEALTH SERVICES
DIVISION OF WATER POLLUTION CONTROL
Hayden Plaza West
4019 North 33rd Avenue
Phoenix, Arizona 85017

June 23, 1971

Mr. Paul DeFalco, Director
Water Quality Office
Environmental Protection Agency
Region IX
760 Market Street
San Francisco, California 94102

Dear Mr. DeFalco:

This letter is in regard to the November 1970 draft entitled "The Mineral Quality Problem in the Colorado River Basin". Copies of this document were reviewed by various persons in the State having an interest in water quality control. Our review of the document indicated that there was very little material that related to the State water pollution control program except in the area of mineral quality. Since the subject matter was principally mineral quality and this subject may have considerable impact on Arizona's existing and planned water resources utilization of Colorado River waters, we requested the Arizona Water Commission to make a thorough review of the material contained therein for possible impact on Arizona.

We have received their comments and a copy of their letter is enclosed. We concur with their comments in their entirety and ask that they be considered as Arizona's official comments on this document.

If you have any questions or comments regarding this matter, please feel free to contact us or Mr. Steiner of the Arizona Water Commission.

Sincerely,

Joseph E. Obr

Joseph E. Obr, M.S.E., Director
Division of Water Pollution Control

JEO:jd

Enclosure

cc: Wesley E. Steiner, Arizona Water Commission
Cliff Tabor, Ariz. Water Quality Control Council
Edmund C. Garthe

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JUN 1971
RECEIVED
ENVIRONMENTAL
HEALTH

June 9, 1971

Mr. Edmund C. Garthe, Arizona Conferee
Colorado River Basin Water Quality Conference
Environmental Health Services
State Department of Health
4019 North 33rd Avenue
Phoenix, Arizona 85017

Dear Mr. Garthe:

This is to present our review comments on the November 1970 draft entitled "The Mineral Quality Problem in the Colorado River Basin" published by the Federal Water Quality Administration of the U. S. Department of the Interior. Observations submitted herein are confined to the substantive issues involved with specific emphasis on the final recommendations which are presented on page 7 in the summary report.

Comments on the Summary Recommendations

No. 1. We strongly support this recommendation. A coordinated state-federal basin-wide salinity improvement program could then be developed under a realistic broad base policy objective.

No. 2,3. These recommendations should be deleted and no effort should be made to adopt numerical salinity criteria until such time as the feasibility and effectiveness of a Colorado River salinity control program can be determined and realistic criteria can be advanced.

No. 4. This recommendation seems unnecessary as qualified existing governmental agencies already have the necessary capabilities and authorities. There is no need to form another agency. The U. S. Bureau of Reclamation has already commenced feasibility studies on some salinity control projects. Because of its role as water master on the Colorado and the interrelationship between salinity and water resources development, we believe the Bureau should assume the primary role in salinity control planning for the Colorado. A recommendation to this effect is in order. It should also be stressed that the development of policy in the comprehensive basin-wide salinity control program should be the joint responsibility of the affected federal and state agencies.

No. 5. We strongly support this recommendation and urge that it be given the highest possible priority.

General Comments on text of Summary Report

Page 14 & 15, (Table I) The hydrologic period used in these studies is not necessarily representative of the average annual flows and conditions for the Colorado River. The period of record of river flows employed in the salinity analysis provides flows lower than those used by most other investigators on the Colorado River. This tends to provide lower predictions of future salinity conditions than would be the case with higher flows and uses. This fact should be recognized in the report.

Page 29, (para. 1, item 3) The assumption that all of the Central Arizona Project water will be used for agricultural purposes is erroneous. The more realistic assumption would be that most of this project water will be utilized by municipal, industrial and other higher value uses by the year 2020.

Page 56 & 57, (para. 4 and following) There would appear to be no basis or justification for expending valuable time, funds, and energies in attempting to establish numerical limits or standards on salinity concentrations until more is known about the optimum quality levels that can be feasibly achieved. Rather maximum effort should first be exerted to determine the feasibility of salinity control programs and their effects on salinity levels.

If you have any further questions regarding these comments or believe that a different position should be presented on these issues, please contact Bob Farrer or myself.

Sincerely,

Wesley E. Steiner
Executive Director

WES:REFe

cc: Cliff Tabor, Chairman
Arizona Water Quality Control Council

CALIFORNIA

STATE OF CALIFORNIA—THE RESOURCES AGENCY
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JEROME B. GILBERT, *Executive Officer*

JUN 4 - 1971

Mr. Paul De Falco, Jr., Regional Director
Water Quality Office, Region IX
Environmental Protection Agency
760 Market Street
San Francisco, California 94102

Dear Mr. De Falco:

In accordance with your letter of April 5, 1971, the State of California has the following comments on your agency's draft report, "Mineral Quality Problem in the Colorado River Basin", dated November 1970. As the State's conferee the State Water Resources Control Board, in cooperation with the Department of Water Resources and the Colorado River Board, has analyzed the draft report and has coordinated the State's reply. In addition, we have solicited the views of the major California agencies receiving water from the Colorado River, and their views are also incorporated herein.

Our comments are divided into three general groupings:

1. Comments on the report's Recommendations and Summary of Findings.
2. General comments on specific subjects.
3. Specific comments on items identified by reference to particular pages.

Our comments on the Recommendations and Summary of Findings are as follows, and the other comments are attached to this letter.

COMMENTS ON RECOMMENDATIONS

Recommendation No. 1

We strongly endorse this recommendation. However, the term "levels presently found" needs definition. We suggest those be defined as the average of the five-year period from 1963-67.

Recommendation No. 2

This recommendation should be deleted. The adoption of numerical criteria should be deferred until the potential effectiveness of Colorado River salinity control programs are better known. Salinity control will be achieved most rapidly by following through with the program outlined in your Recommendation No. 5.

Recommendation No. 3

We see no value in establishing a federal-state task force on numerical salinity criteria at this time. Such a task force should be deferred until more is known about the proposed salinity control measures.

Recommendation No. 4

Existing governmental agencies have the capabilities to carry out the necessary work and there is no need to form another agency. The U. S. Bureau of Reclamation (USBR) has commenced feasibility level studies on some salinity control projects in this fiscal year. Because of the interrelationship between salinity and water resources development and the USBR's long record of activity in the Colorado River Basin, it is the logical agency to assume the primary role in this work. We believe that your recommendation should support the USBR in this role and further recommend that the USBR elevate Colorado River salinity control to the status of a major action program.

Work on the program needs to be expedited. The USBR should be requested to establish a Colorado River Salinity Control Program with a director reporting to the USBR policy level authority in Washington. The director should be able to handle all aspects of the salinity problem including planning, implementation and institutional problems. There is precedent for this approach in handling a major program, inasmuch as the USBR recently established a Director of the Western United States Water Plan Study in a similar instance where a major program involved more than one region.

As the major federal water quality agency, EPA should assist the Salinity Control Program in a consulting and guidance capacity.

Recommendation No. 5

We strongly support this recommendation and suggest that it replace your Recommendation No. 2. The report should outline specifically how your agency would assist in implementing this recommendation. The means of implementation that should be covered in recommendations to this report include: (1) the completion of ongoing research projects funded by EPA, (2) the initiation of additional research projects that would be funded by EPA that may be necessary to prove out the various salinity control measures proposed in the report, and (3) a statement as to the participation by your agency's competent Colorado River Basin Water Quality Office personnel in the feasibility study stage of analysis of the project.

COMMENTS ON SUMMARY OF FINDINGS

Mexico - Colorado River Salinity Problem

The report does not discuss the effect of increased Colorado River salinity on the relations between the United States and Mexico. Mexican officials have stated that the River's salinity is the outstanding problem between the two countries, and discussions have been held by the presidents of both countries on several occasions. It is not necessary to compute what the salinity would be at the Northerly International Boundary without salinity control projects. However, there should be a general discussion of the Mexican salinity problem in the text and a statement in the Summary of Findings that "Major international benefits would accrue to the United States by the implementation of a salinity control program to prevent increased salinity in the Colorado River water to be delivered to Mexico".

Other U. S. Salinity Control Programs

The report makes no mention of the precedent-setting work on salinity control programs in the Arkansas and Red River Basins in Texas and Oklahoma. In order to develop a perspective on the proposed program for the Colorado River Basin, it would be of great value if the report briefly mentioned the work that has been ongoing in that area for over ten years, the projects that have been authorized and the fact that the projects have been wholly federally funded. This item should be included in the Summary of Findings.

It is very important that your final report be released as soon as possible. We do not expect you to make any additional technical analyses because of our comments. It will be adequate to have the text of the report include discussions of our comments in sufficient detail so that a reader would understand the limitations on the data contained in the report and the general effect of other reasonable assumptions.

California appreciates the opportunity of reviewing this report. Our recommendations and comments are offered in the spirit of improving a basically sound document and making it more usable and widely accepted. Prompt issuance of the final report will make a valuable contribution to moving in the direction of preventing damaging salinity conditions on the Colorado River. We hope that the necessary changes will be effected so that the final report can be issued shortly.

Sincerely,

JB Gilbert

Jerome B. Gilbert
Executive Officer
(California Conferee on Pollution
of the Interstate Waters of the
Colorado River and its Tributaries)

Attachment

GENERAL COMMENTS

Upper Basin Depletions

The rate of future Upper Basin depletions is speculative. Estimates have been made by various agencies, including the Bureau of Reclamation in its 1969-70 Mead-Powell Operating Criteria studies, the Upper Colorado River Commission in its 1969-70 studies, the Federal-State 1970 Type I Framework studies for the Upper Colorado Region, and the Colorado River Board in its August 1970 report entitled "Need for Controlling Salinity of the Colorado River." Your projections are lower than those made in all of the above analyses. Your report projects new Upper Basin depletions, including transbasin diversions but excluding evaporation losses of 1,980,000 acre-feet by the year 2010. We believe that more probable projections, taking into account the analyses performed by other agencies, would be for new Upper Basin depletions exclusive of reservoir evaporation of 2,210,000 acre-feet by the year 2000 and 2,400,000 acre-feet by the year 2020.

Increased Upper Basin depletions will result in increased salinity in the Lower Basin. We do not suggest any additional technical analyses. It is recommended that the report state that other responsible agencies have projected higher Upper Basin depletions which would result in higher salinity concentrations.

Effect of Hydrologic Period

The hydrologic period used in your report, 1942-61, results in an estimated average annual virgin flow at Lee Ferry of about 13.4 million acre-feet (maf). This is lower than that used by other investigators on the Colorado River and tends to understate the severity of the salinity problem.

Use of the 1942-61 period understates the potential increase in salinity in the Lower Colorado River Basin for the following reasons:

a. The river's total salt load at Lee Ferry would be smaller under the runoff figures used, in comparison to higher estimates of the river's long-time water supply.

b. With the lower water supply, the Upper Basin is not able to develop to the extent that most other agencies have projected, thereby reducing the salinity effect of such developments.

c. Under conditions of complete Upper Basin use of its water supply, a fixed quantity of water would leave Lee Ferry. The smaller salt load obtained by use of the 1942-61 period carried in a fixed quantity of water will result in lower salinity concentrations than the higher salt load obtained by a larger long-term water supply and carried in the same quantity of water.

California, Arizona, and Nevada, in joint testimony before Congress on the Colorado River Basin Project Act in 1965, stated that the dependable yield of the river's virgin flow at Lee Ferry was about 13.7 to 14 maf/yr, and that there was a 50 percent chance of 14.9 maf/yr at Lee Ferry. At the same congressional hearings, the Upper Colorado River Commission's consulting engineers estimated a virgin water supply of 14.6 to 15 maf/yr. There are substantial spills associated with these volumes of runoff, indicating a dependable supply of about 13.7 maf/yr at Lee Ferry. At the same hearings, the U. S. Bureau of Reclamation used an average annual virgin flow of 15.05 maf/yr.

The August 1970 report of the Colorado River Board of California used 14 maf/yr annual virgin flow at Lee Ferry to determine salinity concentrations. This, combined with more recent estimates of Upper Basin depletions, resulted in a projected salinity at Imperial Dam of 1340 parts per million (ppm) for year 2000, assuming no salinity control projects. Your report projects 1223 ppm for year 2010.

We do not suggest that you change the hydrologic period at this late date or make any additional technical analyses. It is recommended that you state that use of higher water supply figures and higher Upper Basin depletions would result in salinity concentrations that are about 10 percent higher than reported.

Salinity Penalty Costs

Analysis of salinity penalty costs is a difficult and complex problem involving many factors and judgments. We reviewed the factors used in your analysis and compared them with other available material. We believe that the penalty costs developed in the report show the severity of the problem but must be considered minimum values. Our reasons for these conclusions are as follows:

a. In the report, the cost impact on urban uses is related almost entirely to the cost of softening hard water in central system softening plants. A number of recent technical articles and reports have stated that softening costs are only one aspect of the total cost impact in urban areas. A major cost impact is the deleterious effect of water high in salinity and in hardness on water purveyor facilities, on distribution systems, on the water pipes and appliances within and on user premises, and on horticultural effects in residential and urban areas. The cost impact from these causes has been variously estimated by investigators to be no less than $5 per acre-foot of water used per 100 ppm increase in salinity. In addition to these costs discussed in various technical papers and reports, there are the costs resulting from increased use of bottled water, costs of maintaining private swimming pools, and the generally adverse effects of poor taste of high salinity water supplies.

b. The agricultural impacts of high salinity water are also understated in that they are predicated upon the yield-decrement method of analyzing cost impacts. Irrigators in California have not been accepting lower yields in accordance with the yield-decrement method, but have been spending millions of dollars attempting to maintain yields through installation of subterranean tile drains, increasing water applications, and changing to expensive methods of irrigation.

Reconnaissance Investigations

This section (page 63) should be rewritten to bring it up to date. It is our understanding that, since your report was drafted, the Bureau of Reclamation and the former Federal Water Quality Administration completed a joint reconnaissance report on salinity control projects. Based on the joint report and other work that has been done since its completion, there is sufficient reconnaissance information available to allow the commencement of feasibility studies on more than just two of the seventeen projects. More research is needed on the behavior of return flows in agricultural salinity control projects, but this would not hamper the commencement of feasibility studies of salinity control on agricultural projects.

SPECIFIC COMMENTS--SUMMARY REPORT

Page 4, Item 1

The report states that salinity affects 800,000 irrigated acres located in the Lower Colorado River Basin and the Southern California service area. The latest published information (largely 1969 data) shows the following for irrigated acreage, including fallow land in some cases. Thus, the acres affected would be over 900,000.

California	
Imperial Irrigation District	475,700
Coachella Valley County Water District	66,700
Palo Verde Irrigation District	91,400
Bard Irrigation District	12,000
Miscellaneous	7,000
The Metropolitan Water District (estimate)	42,000
Subtotal	694,800
Arizona	
Gila Project	98,300
Yuma Valley	48,000
Yuma Auxiliary	3,300
Colorado River Indian Reservation	51,100
Mojave Valley	4,800
Miscellaneous	12,000
Subtotal	217,500
Total	912,300

Page 4, Items 3 and 4

The resulting salinity is based upon "repetition" of the 1942-61 period and postulated rates of future water use. As previously mentioned, larger water supply quantities have been used to reflect the probable future flow of the river and with related increased depletions. It should be acknowledged that the salinity would be higher with a larger water supply and increased Upper Basin use.

Page 5, Item 7

Since the methods used in the report to determine agricultural, municipal and industrial economic penalty costs excluded certain items, this finding should state that the costs are considered to be minimum values.

Page 5, Item 9a

It should be mentioned that a portion of an imported supply would have to be assigned to salinity control in order to achieve significant long-term improvement at Imperial Dam.

Page 6, Item 9b

The following phrase should be added in the first sentence after the word "pickup,": "reduction of volume of groundwater flow through saline formations by. . . ."

Page 8, Paragraph 3

The Colorado River Compact was signed by the negotiators on November 24, 1922; however, it did not become effective until the President's proclamation of June 25, 1929. Accordingly, we suggest adding the words "which went into effect in 1929," after the year "1922."

Pages 11 and 12

The writeup under "Water Compacts" should be corrected and expanded. Page 11, first paragraph, third line, replace "three" with "four"; fourth line, strike out "signed in 1922"; fifth line, strike out "and"; and in the sixth line, add the following: ", and by the Supreme Court Decree of 1964 in Arizona v. California."

Page 11

Fifth paragraph, sixth line, capitalize "Upper Division."

Page 11

Fifth paragraph, after the last line add "Any water committed to Mexico . . . shall be supplied first from the waters which are surplus . . ."; and ". . . if such surplus shall prove insufficient for this purpose, then the burden of such deficiency shall be equally borne by the Upper Basin and the Lower Basin . . . ."

Page 12, Paragraph 1

Delete the last line and substitute the following: "The Lower Division apportionment was divided among the Lower Basin states--Arizona, California, and Nevada--by the decree of the United States Supreme Court in 1964 which states that apportionment was accomplished by the Boulder Canyon Project Act of 1929. If Colorado River mainstem water is available in sufficient quantity to satisfy 7,500,000 acre-feet of annual consumptive use in the three Lower Basin states, Arizona, Nevada, and California are apportioned 2,800,000, 300,000, and 4,400,000 acre-feet, respectively."

Page 12, Paragraph 2

The 1965 gross California diversions of 5.35 million acre-feet from the Colorado River were for use in both the Colorado Basin and Southern California service area portions not just the "Southern California service area." The diversions less measured returns to the river which approximate the Supreme Court Decree definition of consumptive use were 4.90 million acre-feet. The latter value should be used and the description changed to include the California areas in the Lower Colorado area.

Page 12, Paragraph 3

Inasmuch as the report earlier separated water uses in the Southern California service area from inbasin uses, this distinction should be maintained. The discussion in this paragraph apparently makes no such distinction and should be revised accordingly. We also suggest striking out the first sentence, as it is redundant.

Page 17, Second Paragraph

In this and subsequent paragraphs, it should be clearly stated that the salt load data shown for Lake Mead or the "above Hoover Dam" point include the salt loads shown for the Upper Basin.

Pages 17 and 18, Section Headed "Present and Future Salinity Concentrations"

Our prior comments pertaining to the use of the 1942-61 hydrologic period should be applied to this section. It should be revised to include a brief discussion of the impact on Lower Basin salinities of higher runoff and resulting increases in Upper Basin depletions.

Page 20, Paragraph 2

It appears that, through examination of Appendix B, the irrigated agricultural expansion now under way on the Colorado River Indian Reservation was not taken into account for the conditions of limited development postulated in this paragraph. The full expansion planned on this reservation will result in a significant increase in salinity at Imperial Dam and should be acknowledged in the report.

Page 20, Last Paragraph

The statement in the first sentence regarding a relatively constant salt load for the next 40 years and the statement in the last sentence pointing out increases in salt loading appear to be in conflict.

Page 23, Paragraph One

The term "threshold level of sensitivity" should be explained in more detail.

Pages 23 through 27

The discussion of the effects of salinity on beneficial uses of water and direct economic effects upon water users should be expanded along the lines discussed earlier. While we do not believe that it is necessary to develop revised numerical results, it should be mentioned that the results are considered to be minimum values.

Table 7, Page 41

The salinity control programs shown in Table 7 that are based on flow augmentation should not be considered alternatives and compared on an equal basis with the other possibilities listed in the table. At this time, these flow augmentation alternatives are subject to such great uncertainities that their inclusion in the table is more likely to cause confusion and result in misleading conclusions as to the best course of action. For example, weather modification is now only in the research phase. Accordingly, we recommend that costs associated therewith be omitted, together with explanatory footnotes. We also recommend that augmentation by geothermal sources be included in the table and briefly discussed in the text.

SPECIFIC COMMENTS--APPENDIX A

Page 85

The report states that irrigation in the San Rafael River area contributed 100 tons of salt per day to the Price River. This should be corrected.

SPECIFIC COMMENTS--APPENDIX B

Page 6

The discussion of the effects of salinity on domestic uses of water should acknowledge bottled water costs, additional costs of maintaining private swimming pools, and costs related to horticultural use of softened water as a result of high sodium concentration, even though not evaluated in your determination of penalty costs.

Page 18

The second full paragraph concludes that soils in the southwest will generally accept an increase in the amount of irrigation water applied for leaching. This conclusion is questionable since there are major irrigated areas in the southwest requiring elaborate drainage systems.

Page 26

The statement on groundwater in the last sentence of the second full paragraph should be deleted since it is not accurate for the entire basin.

Page 46

The first full sentence states the mean annual virgin flow at Lees Ferry for the period 1942-61 to be 13.8 maf. Records published by the USBR show the virgin flow for that period to be 13.35 maf.

Pages 48 and 49

The projected future depletions in the Colorado River Basin, which are shown in Table 12, appear low. Projections of future Upper Basin use made by the USBR indicate higher levels than shown in Table 12. The irrigated agricultural expansion on the Colorado River Indian Reservation is not shown.

Pages 53 and 54

The projections of future salinity presented in Table 13 and Figure 5 are low in comparison with projections developed for the Type I Framework Studies and by the Colorado River Board of California in its August 1970 salinity report.

Page 61

The first two sentences of the first paragraph indicate that water users in the Lower Basin have recently begun to recognize that degradation of Colorado River water is having an adverse effect on their economic welfare and that, although individual users have not felt the impact to a significant degree, there is a general awareness of the problem. These sentences are misleading. Large numbers of Lower Basin domestic, industrial, and irrigation users of the Colorado River have been keenly aware of the river's salinity on their economic welfare for a number of years.

Page 67

It is not clear how the quantity of applied water required for a crop at a given salinity can be obtained from the formula.

Page 70

The formula for leaching requirement is not as described in Handbook 60 published by the U. S. Department of Agriculture. The formula and its description need clarification.

Page 77

The discussion of the methods used to evaluate additional labor costs and fertilizer losses is not understandable and needs clarification.

The last paragraph states that drainage facilities were assessed no penalty costs because (1) irrigation districts build facilities as they are needed, (2) additional leaching water required because of water quality degradation can easily be carried by the existing closed systems. With regard to the first reason, irrigation districts must build facilities or expand existing facilities to accommodate additional leaching water. Reason (2) is incorrect in many cases.

Page 78

It should be mentioned that the yield-decrement method for irrigated agriculture gives minimum penalty costs. Large expenditures have been and are being made to expand and improve drainage systems in the Imperial and Coachella Valleys among other areas using Colorado River water.

Pages 78 and 80

Industrial penalty costs were evaluated for only cooling and boiler feed. Even though the report indicates that industrial penalty costs are somewhat understated, the report should acknowledge in general terms all other penalty costs not included in the industrial uses

Page 93

The effects of softening should mention two important factors:

a. When home regenerated softeners are used, only about one-half of the delivered water is softened. The remaining one-half is used for irrigation of lawns, etc., and is not ordinarily softened.

b. Central softening by the Metropolitan Water District raises the sodium percentage to about 75 percent which removes about two-thirds of the hardness. Hardness is not reduced further because of (1) cost, (2) deleterious effects of high sodium water on existing chemical deposits in pipelines of many member agencies, and (3) deleterious effects of high sodium water for irrigation.

Pages 93 and 95

Penalty costs associated with municipal use of water in the Southern California water service area were calculated as being the costs associated with large central softening plants for the Metropolitan Water District service area and the City of Calexico. Soap wastage costs were used as penalty costs for the remaining areas of California. A number of reports prepared by private engineering firms and public agencies concerning the value of the quality of Colorado River water in Southern California are available and indicate that penalty costs developed in this report would be minimum values. When plumbing and appliance replacement costs, bottled water costs, household water softening costs, etc., are considered, penalty costs will be significantly greater than those projected by this report.

Pages 100, 103 and 104

It is realized that the assumptions in the report regarding quantities of water from the Colorado River and the State Water Project and their blending may have been reasonable several years ago when the report was in preparation. However, we now have better knowledge of the limitations of existing distribution systems and estimated quantities of water planned for importation and use from available sources. The information on quality of water to be expected by blending is oversimplified and misleading. In addition, if timing for construction of the Peripheral Canal of the State Water Project is not adhered to for any reason, deliveries from that source could have significantly higher salinities than shown in your report after 1980. We therefore recommend that Figure 15 be removed from the report.

STATE OF CALIFORNIA—THE RESOURCES AGENCY
RONALD REAGAN, Governor

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JUL 12 1971

Mr. Paul De Falco, Jr.
Regional Director
Water Quality Office, Region IX
Environmental Protection Agency
760 Market Street
San Francisco, California 94102

Dear Mr. De Falco:

This letter is in further response to your letter of April 5, 1971, regarding your agency's draft of the report "Mineral Quality Problem in the Colorado River Basin" dated November 1970. We should like to amend one statement made in our specific comments on items identified by reference to particular pages that was appended to our letter of June 4, 1971, regarding this subject.

Pages 9 and 10 of our specific comments referred to pages 100, 103, and 104 of Appendix B and recommended that Figure 15 be removed from that appendix. We should like to amend that statement by substituting the following discussion:

> The report discusses the blending of water from the State Water Project with that from the Colorado River. In order to make the discussion more current and accurate, we suggest inclusion of the following points. The Metropolitan Water District of Southern California has given this matter extensive consideration during the past year and is continuing to study the relationships involved. Because of the limitations of existing distribution systems and facilities now scheduled for construction during the period covered by the discussion on these pages, complete blending to the extent shown in the report will not be possible. In addition, reduction of imports of Colorado River water due to the effects of diversions by the Central Arizona Project will probably not occur as early as shown in the report. As a result, improvement of quality would be delayed somewhat. In addition, if timing for construction of the Peripheral Canal of the State Water Project is not adhered to for any reason, deliveries from that source could have significantly higher salinities than shown in the report after 1980.
>
> Even though Figure 15 and the analysis it depicts are not completely current and accurate, we believe that they are satisfactory for the purposes of the report and should be included.

Again, California expresses its appreciation for the opportunity of reviewing this report. We trust that this change in our original comments will be acceptable and will not unduly inconvenience you.

Sincerely,

Jerome B. Gilbert
Executive Officer

COLORADO

STATE OF **COLORADO** DEPARTMENT OF **HEALTH**
4210 EAST 11TH AVENUE · DENVER, COLORADO 80220 · PHONE 388-6111
R. L. CLEERE, *M.D., M.P.H., DIRECTOR*

June 2, 1971

Mr. Paul De Falco, Jr.
EPA WQO
760 Market Street
San Francisco, California 94102

Review of Preliminary Draft "The Mineral Quality Problem in the Colorado River Basin"; Summary Report, Appendices "A", "B", and "C"

There has been no attempt by this Division to evaluate the input data used in the preparation of this report. Lack of manpower and the time allotment imposed for comments have precluded an evaluation of all but the general recommendations and conclusions as presented in the Summary Report.

It is difficult to follow the various estimated costs for salinity control throughout this report. Nomenclature and terminology changes and different salinity levels tend to confuse and obscure the various estimated costs. If phased implementation as the minimum cost objective (with a target level of 800 mg/l at Hoover Dam) is to be the recommendation, then this alternative should be developed in a straight forward manner with total costs, benefits, detriments, and methods of implementing controls clearly stated.

Page 6 of the Summary Report states: "A basinwide salt load reduction program designed to minimize total salinity costs (detriments plus control costs) would have an estimated average annual cost of $7 million in 1980 and $13 million in 2010 (1970 dollars)." This is in general agreement with total salinity management costs from Table 9, Summary Report, page 53; however, total annual salinity management costs in Table 9 indicate only $5.9 million in 1980 and $10.8 million in 2010 as the cost of irrigation improvements. This does not appear to be compatible with Table 8, Summary Report, page 42, which estimates average annual total project costs of $46.7 million and average annual salinity control costs of $34.8 million. Estimated costs in Table 8 are apparently based on 700 mg/l at Hoover Dam rather than 800 mg/l.

Implementing the first 13 projects in Table 8 as the phased implementation alternative for salinity control, would have average annual costs of $12.7 million with $10.8 being for irrigation improvement. This agrees with the estimated average annual cost in 2010 for irrigation improvements in Table 9. However, the text in Appendix C indicates the implementation of these 13 projects by 1980 (Appendix C p.v-14 and v-24). This raises the question of the estimated annual irrigation improvements cost in 1980, is it to be $5.9 or $10.8?

Table 9, page 53, Summary Report, is also misleading in the fact that for irrigation improvements only one half the project costs are listed for salinity control costs. Total local investment cost per year to achieve the control desired would be $13.1 million in 1980 and $23.5 million in 2010 instead of $7.2 million and $12.7 million as listed. Even though the differences are for benefits other than salinity control, the total project costs should be incorporated into Table 9 to give a true picture of the expenditures necessary to accomplish the recommendations. Table 9 also would give the impression that local investment costs are only one half the irrigation improvement costs whereas all the irrigation improvement costs are to be local investment and comprise 82 percent (1980) and 85 percent (2010) of the total salinity management costs. It is recommended that Table 9 be omitted from the report and be replaced with a similar Table which lists T.D.S. objective,total irrigation project costs, and indicate that all salinity management costs for irrigation improvements are by local investment.

In the comparison of alternative salinity control programs (Summary Report page 41) there is no alternative developed for phased implementation with salinity concentration of 800 mg/l at Hoover Dam as the objective. If this is to be the recommendation (S.R. page 7) then this alternative should be developed. Incidentally, the estimates in Table 7 do not appear to agree with estimates in Table 9 for a constant salinity level of 700 mg/l. What is the difference between "Average Annual Program Cost" (Table 7) and "Total Salinity Management Costs" per year (Table 9)? The average annual program costs as developed in Table 7 are much higher than the total annual salinity management costs as estimated in Table 9. In fact, the average annual program costs for all but two of the alternatives developed in Table 7 exceed the total economic detriments with no salinity controls and unlimited development.

Item 8 on page 5 of the Summary Report states: "More than 80 percent of the total future economic detriments caused by salinity will be incurred by irrigated agriculture located in the Lower Basin and the Southern California service area.." It would follow then that more than 80 percent of the benefits of a salinity management program will accrue to these same areas. These benefits are stated to be $11 million in 1980 and $22 million in 2010 (S.R. p.6). The phased implementation program requires the construction of the first 13 projects in Table 8 (S.R. p. 43) all of which are located in the Upper Basin. Average annual local investment costs for salinity control to the Upper Basin States then would be $5.9 million in 1980 and $10.8 million in 2010 (Table 9.) Salinity control benefits to the Upper Basin States would be $2.2 million in 1980 and $4.4 million in 2010 (20 percent of benefits). In all probability, cost to benefit ratios such as these will be received somewhat less than enthusiastic by the Upper Basin States.

Page 55 of the Summary Report concludes that salinity concentrations increase substantially between Hoover Dam and Imperial Dam due to water use in the Lower Basin and exports to Southern California. Implementation of salinity control measures in the Lower Colorado River could effect or minimize the salinity increases below Hoover Dam; however, since the unit costs were higher than for the minimum cost program, these measures were omitted from consideration. The cost index for the minimum cost objective program range from $3.89 per ton to $32.00 per ton of salt removed (Table 8 p. 43). It would be interesting to know the cost index for control projects below Hoover Dam. It could be that implementation of salinity control measures in the Lower Basin would result in a more equitable cost distribution than the minimum cost objective as recommended. The report further states on page 55 that: "Salinity control below Hoover Dam,however, is a possible, practical approach toward minimizing the economic impact of salinity and should receive further consideration in the formulation of a basinwide salinity control program." Investigation and consideration of these measures should be made before adoption of final recommendations by the conferees.

"Existing legal and institutional arrangements are not adequate to provide the basis for implementing a largescale salinity control program." (S.R. p.60) "Detailed evaluation of existing legal and institutional constraints which may affect the basinwide salinity control program should be conducted." (S.R. p.64) These statements reflect the crux of a basin wide salinity control program and raise some interesting questions. If a salt load reduction program removed 172,000 acre feet of water above Hoover Dam (S.R. p.42) would this water have to be replaced by the Upper Basin States to meet requirements of the Colorado River Compact? If irrigation improvements reduced consumptive use by 299,000 acre feet annually in the Upper Basin, would this flow be available for flow augmentation or could this flow be captured and used by owners of downstream water rights? A determination of the modifications needed in existing legal and institutional constraints and means to accomplish these modifications should be made prior to an attempt to implement salinity controls. We reject the recommendation on page 60 that congressional authorization be sought at an early date so that implementation of the salinity control program can proceed. Attempting to modify existing legal constraints by congressional action may not be politically expedient and could jeopardize any and all salinity control programs.

A broad water quality objective to minimize the future economic impact of salinity in the Colorado River Basin is desirable and should be adopted by the conferees. A statement endorsing this objective should be qualitative rather than quantitative however. Until such time as the research and demonstration projects have actually demonstrated the practical methods of salinity control, the adoption of interim numerical standards would serve no useful purpose at this time.

We agree with the statement in the first paragraph on page 57 of the Summary Report which states: "Although additional information will be required before it will be possible to establish detailed basinwide criteria which are equitable, workable, and enforceable", we disagree with the remainder of the statement, "present information is considered adequate to form the basis for the establishment of interim salinity standards which will set an upper limit on salinity increases in the Lower Colorado River".

The adoption of interim numerical criteria by the Upper Basin States that for any given month the average concentrations of total dissolved solids be maintained below 800 mg/l at Hoover Dam and 1000 mg/l at Imperial Dam would require the Upper Basin States to adopt water quality standards and stream classifications limiting salinity concentration considerably below the present levels. Since much of the salt load and concentrating effects are from irrigation return flow and other diffuse sources the surveillance and monitoring of these salt sources would be extremely difficult and enforcement next to impossible under existing legal constraints. The adoption by the States of interim numerical standards which are impossible to enforce will in no way contribute to the solution of the water quality problem of the Colorado River Basin. In Colorado a special classification for the Colorado River and its tributaries would be necessary as the salinity concentration in the Colorado River is much less than the salinity concentration of the South Platte and Arkansas Rivers. Although this would be possible, the implementation of a double set of standards for the same use would probably result in extreme criticism and possible legal action by the local interest affected.

For the present we would favor the continuation of the present Task Group to develop policy and plan a basinwide salinity control program. As mentioned in the Summary Report no new legislation would be required for this approach. The creation of a State/Federal River Basin Commission with arbitary authority over all activities necessary for basinwide management and control of salinity is not favored at this time. We would need to know much more about the method of funding and details of the plan of implementation before abrogating the powers and duties of the Colorado Water Pollution Control Commission in the Western half of the State.

Thank you for the opportunity to review and comment on this preliminary report.

FOR DIRECTOR, WATER POLLUTION CONTROL DIVISION

Kenneth W. Webb, P.E.
Public Health Engineer

KWW:mgc

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May 28, 1971

RECEIVED
JUN 1 - 1971
WATER POLLUTION
CONTROL DIVISION

Mr. Frank Rozich, Director
Water Pollution Control Division
Colorado Department of Public Health
4210 East 11th Avenue
Denver, Colorado 80220

Dear Frank:

Enclosed are the comments of the Colorado Water Conservation Board in the Summary Report of The Mineral Quality Problem In The Colorado River Basin dated November, 1970. As you know this Summary Report was issued by the Federal Water Quality Administration and they are asking that all Colorado comments be channeled through you as the Colorado conferee. They are also asking for the comments by June 7, 1971.

I have reviewed the draft of the prepared comments of your office and it appears that we are both thinking along the same lines.

Sincerely,

L. D. Morrill

L. D. Morrill
Deputy Director

LDM/ac

Enc.

The Mineral Quality Problem In The
Colorado River Basin Dated November 1970
Federal Water Quality Administration

General Comments:

The use of the 1942-1961 period of hydrologic record for estimating average salinity conditions for future years makes projected values too high. For example, present concentrations below Hoover Dam are about 725 mg/l, but projection shown for 1970 is 760 mg/l. The report should be updated using a more typical period of record. A report that is ten years out of date and that uses a period of record that is not average is of questionable value.

While the report states that it does not recommend curtailment of future water resources development as a means of salinity control, it mentions this possibility in several places. The state of Colorado completely rejects this concept of restricting development in the upper basin for the benefit of the lower basin California and Mexico simply because they developed or are developing their water resources ahead of the upper basin. One of the primary reasons for the Colorado River Compact was to insure that the upper basin states would have water for this future development even though they didn't use their full allocation for many years.

Since the major benefits of any major salinity control measures would accrue to water uses in the lower basin, California and Mexico the costs should not be borne by the upper basin. It is recommended that since it would be extremely difficult to apportion the costs in an equitable manner, and still more difficult to collect the money from the beneficiaries in accordance with the benefits received, that such control measures be a federal cost. This would be similar to the present flood control projects of the Corps of Engineers.

It would also seem unrealistic and quite futile to establish salinity standards until a salinity control program complete with a practical method of financing such a program has been established.

Specific Comments

Page	Paragraph	
4	3	As previously stated, the 1942-1961 period is not typical and projection and conclusions based on the use of this period are misleading. Delete reference to limiting to development of water resources as a means of salinity control.
4 & 5	4	This paragraph is highly conjectural and argumentive and adds little to the value of the report. It should be deleted.
5	5	The 1960 data should be updated to 1970.
5	6	The first sentence of this paragraph may not be accurate.
5	7	This paragraph may be based on questionable assumptions. Apparently no consideration is given to offsetting benefits due to water development. The last part of the paragraph again dwells on limiting future water resource development and should be deleted.
6	C	This paragraph again dwells on limiting water resource development and should be deleted. Would recommend concentrating on the concept as expressed in paragraph a and b.
6	11	The fourth and part of the fifth line are repetitive and should be eliminated.
7	1	This may not be possible to achieve. A realistic program should be set up ahead of such recommendations.
7	2	Same comment as for paragraph 1
7	3	Same comment as for paragraph 1
7	5	Shouldn't be in too much of a hurry to implement a basin-wide salt load reduction program. A comprehensive and realistic approach to this problem is needed.
11	2	The accuracy of the last sentence of this paragraph should be checked.
12	1	The apportionment mentioned in the last two sentences was by the supreme court, not by the Upper Basin Compact.
13	1	The third from the last sentence states that "No comprehensive evaluation of present or future mineral quality had been made." What about USGS Professional Paper 441 from which much of the data on salt loads was obtained?

Specific Comments

Page	Paragraph	
14 & 15	1	This table should be adjusted to 1970 conditions and should use a more typical period of record.
17	2	In table 2 a figure of 5,760 is shown under the salt load leading. This figure is 5,408 in table 1, page 14.
18	3	In the third from last line, the word by should be changed to be.
		In figure 2 following page 18, date should be revised to reflect a modification to 1970 conditions.
20	1 & 2	Reference to limited development conditions in these paragraphs and table 3 should be deleted.
23	1	Who determines the threshold limits and how authentic are they? Also, the salinity of the Salton Sea will continue to increase even with present water quality because of salt concentration by evaporation. What is the marine fishery worth?
28		The values in table 5 should be converted to 1970 dollars.
29		The statement at the top of the page says "It was assumed that all Central Arizona Project water would be used for agricultural purposes." This assumption is erroneous.
		Figure 4 following page 29 doesn't state what dollars were used. 1960?
33	B-2	It is questionable that treatment or disposal of return flows from irrigation to cut down salinity is physically or economically practical.
39	2	This paragraph makes the statement that limiting water resource development that is expected to produce an increase in salt loads or streamflow depletions has the disadvantage of possibly stagnating growth of the regional economy. This is a gross understatement. Any development that uses water causes stream depletion and many contribute additional salinity. Since practically all resource developments use water, such an approach would stop further economic development.
41		What year dollars were used in table 7?
42	3	Is there any good backup basis for the assumption that only half the costs of irrigation improvement were allocated to salinity control? It might be nearer 75% to 80%.
		What year dollars used in table 8 following page 42?

Specific Comments

Page	**Paragraph**	
		What year dollars used in figures 6 and 7 following page 45?
		What year dollars in figures 8 and 9 following page 49?
		What year dollars in table 9 following page 53?
56	2	This paragraph states "the feasibility of maintaining salinity concentrations at a below present levels in the Colorado River below Hoover Dam has been shown." This is not true. Nowhere has it been shown that anybody is willing to pay for this. Requiring salinity concentrations to be maintained at or below present levels in the Lower Colorado River would be an exercise in futility without a practical method of financing such a requirement.
56 & 57		Setting salinity standards is futile without some economically and politically practical method of achieving these standards.

NEVADA

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STATE OF NEVADA
DEPARTMENT OF HEALTH, WELFARE, AND REHABILITATION
DIVISION OF HEALTH
CARSON CITY, NEVADA 89701

June 4, 1971

Environmental Protection Agency
Region IX
760 Market Street
San Francisco, California 94102

Attn: R. L. O'Connell
Acting Interim Regional Coordinator

Dear Mr. O'Connell:

Concerned State agencies have reviewed the draft report of the Mineral Quality Problems in the Colorado River Basin dated November, 1970, and have the following comments:

There are several technical errors in the report which are apparently in part a result of the length of time involved in preparation of the report. The errors in quantity, and salinity determinations as well as in the cost estimates will require considerable revisions but do not have significant impact on the findings and recommendations in the report. These errors can be more specifically spoken to if the Environmental Protection Agency determines to rewrite the report before reconvening the enforcement conference.

We concur with the findings that a basinwide salt load reduction program at present appears to be the most feasible approach for maintaining salinity concentrations at acceptable levels but cannot agree with all the recommendations for implementing the program.

We concur with Recommendation 1 for adoption of a broad policy objective for the entire basin to maintain salinity concentrations at or below present levels in the lower Colorado and with Recommendation 5 that measures be taken immediately to obtain authorization and funding to implement the policy objective.

We do not agree that total dissolved solids numerical standards should be adopted at this time as suggested in Recommendation 2. Until there is assurance authorization and funding will be available to implement a control plan this would appear to be an exercise in futility. The broad policy objective can be oriented towards specific quality to provide interim goals.

We do not agree to the establishment of a federal/state task group for development of additional salinity control criteria at key points as suggested in Recommendation 3. Such additional criteria in keeping with the broad policy objectives could be more readily established by the individual states and appropriate federal agencies.

We do not agree with Recommendation 4 which suggests establishing a state/federal or river basin commission to plan, formulate policy, direct and implement a basinwide salinity program. Formulation of policy and direction should be the joint responsibility of the concerned state and federal agencies. Implementation could appropriately be extended to an existing agency such as the Bureau of Reclamation which has a competency in program development, design and construction. River basin or regional planning in various programs as is being required under federal law and regulations must consider all elements such as water pollution control, water resources and use, fish and wildlife, recreation, land use and management, watershed management, population concentration, transportation habits and pattern, etc., if comprehensive plans are to be developed for any single element. To isolate a portion of an element, such as salt loading in water pollution, with disregard for its relationship to the total water pollution problem and in turn this relationship to the other essential elements will only add to the confusion and duplication existing in all levels of government in planning efforts. State and local agencies engaged in planning activities must have an input into program policy for all elements if planning is to be effectively implemented. The Colorado River Basin states must assist in establishing basin-wide salinity control program policy as affects their areas of concern and kept informed on all aspects of program development to relate this program to their other planning elements.

We appreciate the opportunity to comment and will await your decision as to whether or not the report is to be rewritten before the conference is reconvened.

Sincerely,

E. G. Gregory, Chief
Bureau of Environmental Health

EGG:ve

cc: Roland Westergard
Don Paff

NEW MEXICO

DATE 7-13-71
FILE

STATE OF NEW MEXICO
HEALTH and SOCIAL SERVICES department

ENVIRONMENTAL IMPROVEMENT AGENCY
P. O. BOX 2348. SANTA FE. NEW MEXICO 87501

Phone No. 827-2373

July 6, 1971

Mr. Paul De Falco, Jr., Director
Environmental Protection Agency
Water Quality Office
760 Market Street
San Francisco, California 94102

Re: Comments on Mineral Quality Problem in the Colorado River Basin Summary Report - Preliminary Draft Dated November, 1970 - Prepared by Colorado River Basin Water Quality Control Project

Dear Mr. De Falco:

You transmitted the above referenced reports to this office for review in April, 1971, and requested that comments be submitted no later than May 3, 1971. This time frame was an impossible one for our Department to comply with, and your office graciously approved an extension of time for us to reply. The scope and complexity of the problem, and the manpower available to review and comment on the documents, made it impossible to comment until now.

I wish to thank the people associated with the Colorado River Basin Quality Control Project for their efforts in developing these comprehensive reports and, as you are well aware, it would have been impossible for the individual states to undertake such a complex study.

I would like to discuss the recommendations which were outlined on page 7 of the Summary Report.

> 1. "A broad policy objective to be adopted for the entire Colorado River System which would result in salinity concentrations being maintained at or below levels presently found in the Lower Colorado River."

Recommendation #1 appears to be a good basic policy for the control of salinity in the Colorado. However, one basic problem with the broad objective is that it does not take into consideration the rights to water development under existing water laws. For that reason, I would suggest that the recommendation be amended to read:

> A broad policy objective to be adopted for the entire Colorado River System which would result in salinity concentrations being maintained at or below levels presently found in the Colorado River without limiting or altering any state's right to water development under the existing water laws.

Emphasis added to portion requested for addition to the recommendation.

2. "Criteria for salinity concentrations to be adopted by appropriate Colorado River Basin States in accordance with the Federal Water Pollution Control Act, as amended.

   As a minimum, these criteria should require that for any given month the average concentrations of total dissolved solids be maintained below 800 mg/l at Hoover Dam and 1000 mg/l at Imperial Dam."

The first portion of this recommendation was discussed by the Conferees' Resolution of November 15, 1967. At that time, the Conferees did not believe it appropriate to develop a numerical standard and specifically stated "that the Conferees do not believe it is appropriate that a standard of 1000 mg/l or any other definite number for TDS at Imperial Dam be set by the Basin States or the Secretary of the Interior at this time." The Conferees further urged the completion of water quality reports and urged FWPCA to consider approval of water quality criteria standards of the seven Colorado River Basin States contingent upon ultimate establishment of acceptable numberical salinity standards. The development of these reports, among other things, was intended to provide basin states with information needed for the development of numerical water quality standards. There is not sufficient information in the report to permit the development, at this time, of numerical standards as recommended in Recommendation #2. For this reason, I would like to recommend that Recommendation #2 be rewritten to read:

> Criteria for salinity in the Colorado River be retained as now adopted. When sufficient salinity control projects are in operation and have been evaluated, and other necessary information is available, salinity criteria could then be adopted. The criteria should provide under full development of the water and completion of salt load reduction programs that for any given year the average concentrations of total dissolved solids be maintained at or below present levels.

3. "A State/Federal Task Group immediately be established to develop additional salinity control criteria at key points throughout the Basin which will accomplish the objective of Recommendation #1. These criteria should be adopted on or

> before January 1, 1973, by the appropriate Colorado River Basin States in accordance with the Federal Water Pollution Control Act, as amended."

This recommendation appears to be superfluous because there presently exists a State/Federal Task Group. The group is the Office of Water Quality, in cooperation with the Conferees. Only with the information in this report, evaluation of completed salinity control projects, evaluation of completed development projects, and with additional studies will it be possible to establish meaningful salinity objectives at key points throughout the Basin. It would be impossible to complete such an undertaking by January 1, 1973. For these reasons, I would respectfully recommend that the following new language be substituted for Recommendation #3:

> The State/Federal Task Group presently established, consisting of the Office of Water Quality and the Colorado River Basin Conferees, should work toward the establishment of salinity objectives at key points throughout the Basin.

4. "The possibility be explored of extending the authority of one or more existing agencies to assume the responsibility to plan, formulate policy, direct, and implement a comprehensive basinwide salinity control program. In the event existing authority is lacking or inappropriate, legislation should be sought to establish a permanent Federal/State agency or River Basin Commission which could assume such responsibility."

Recommendation #4 has far-reaching implications and could be construed as recommending interstate compacts on quality. It is realized that a State/Federal agency or River Basin Commission could be assigned such responsibilities as presently being handled by such interstate agencies as ORSANCO. This recommendation, however, if implemented, could have the effect of establishing a new agency and could require the development of a compact on salinity. The establishment of any such compacts or agreements would be, in effect, amending the present water laws. The present water law, in apportioning water for consumptive use has, in effect, already committed the States to that quality of water which will be realized as a result of beneficial consumptive use of the waters allocated to the individual states. For these reasons, I suggest that Recommendation #4 be deleted.

5. "Early measures be sought to authorize, fund, and implement a basinwide salt load reduction program that would lead to achieving Recommendation #1."

Recommendation #5 should definitely be included in the report and actively supported by the Water Quality Office and the Basin States. I particularly support Recommendation #5 in order that salinity control measures can be implemented at the earliest possible time to maintain the water quality of the Colorado River in the best condition possible.

I would like to make some additional editorial comments on the proposed draft of the Summary Report:

Page 4, paragraph numbered 2, under Chapter 2, Summary of Findings and Recommendations: It is noted that out-of-basin export is included with the salt concentrating effect consideration. I believe that the full ramifications of out-of-basin export should be discussed in paragraph 2. The full ramifications of out-of-basin export are explained in detail in other areas of the report. However, for someone reading only the Summary, the wrong inference could be drawn.

Page 6, paragraph C, discusses the unreasonable, unlawful, and totally unacceptable concept of curtailment of future water resources development in order to achieve salinity control. Paragraph 10 on page 6 further mentions that partial implementation of the other two alternatives (one of which would be curtailment of uses) would increase the effectiveness of the salt load reduction program. I cannot support the limitation of further development of water allocated New Mexico under present water law.

The Secretary of the Interior in a letter dated February 2, 1968, stated that "After consideration of all the factors involved, I have decided that salinity standards should not be established until such time as we have sufficient information to be reasonably certain that such standards will be equitable, workable, and enforceable. Arriving at this decision at this time does not and will not preclude initiating of programs to study and demonstrate the feasibility of controlling and alleviating the Basin's salinity problem."

In a letter dated February 12, the Assistant Secretary for Water Pollution Control, made the following statement: "It is the intention of the Secretary that the Department of the Interior and States pursue active programs to lay the foundation for setting numerical criteria at some future time. These programs should focus on devising and demonstrating salinity control measures and finding ways to revise the legal and institutional constraints that could impede the implementation and enforcement of salinity standards."

It is unfortunate, but a fact of life, that information is not available in sufficient detail and scope to permit the development of salinity standards at this time. I recognize the need for and endorse a program of salt reduction projects and believe they should be considered in the total scheme of river development. I also believe we should be striving for a river quality objective which permits beneficial use of the river for generations to come. It must be perfectly clear when developing objectives that nothing be included that will preclude any state from her rightful share of Colorado River water under present water law. For these reasons, I recommend that criteria for dissolved ionic constituents be framed as objectives to be achieved.

I recommend that the project be continued with the specific understanding that working in cooperation with the Basin States and other Federal agencies, the project will develop information for establishing objectives at strategic points throughout the Basin.

In summary, I recommend that feasibility studies of salinity control programs be undertaken at the earliest possible time and the project be continued whereby objectives can be developed as guides and framework for establishment of criteria that will be equitable, workable, and enforceable. Until such time as criteria can be set, the objectives can be used for Basin planning and the basis for decisions in developing salinity control projects and ancillary State standards and regulations.

Please note the change of address and be advised that there has been a change in agency responsibility. As of July 1, 1971, this office will be the Water Quality Section of the Environmental Improvement Agency.

Transmitted herewith are comments prepared by the New Mexico Interstate Stream Commission. This office is in basic agreement with the Interstate Stream Commission's position. However, I recommend that the project be continued with the responsibility to develop tributary by tributary objectives to be used as guides and framework for the Basin States' consideration when ultimately developing criteria.

Yours truly,

John R. Wright

John R. Wright, P.E., Chief
Water Quality Section Conferee

JRW:fl

cc: Director
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RICHARD P. COOK, Espanola

LEGAL ADVISER
CLAUD S. MANN, Albuquerque
Charles M. Tansey
Farmington

June 24, 1971

Mr. John Wright, Chief
Water & Liquid Waste Section
Health & Social Services Department
PERA Building
Santa Fe, New Mexico

Dear Mr. Wright:

By letter dated April 5, 1971, Mr. Paul DeFalco, Jr., Director of the Water Quality Office of Region IX of the Environmental Protection Agency transmitted to the New Mexico Interstate Stream Commission a copy of a draft report on "The Mineral Quality Problem in the Colorado River Basin". He requested that the Commission furnish its comments on the report through you by May 3, 1971. By letter dated April 19, you requested that the time allowed for the state to furnish its comments be extended to July 1, 1971. The time allowed was extended to June 7 and on about that date you advised Mr. DeFalco by telephone that an additional 10 to 20 days would be required for the state to complete its review and comment on the report.

The comments of the Interstate Stream Commission are set out below. It is requested that you furnish a copy of this letter to Mr. DeFalco.

Each of the five "RECOMMENDATIONS" set forth at page 7 of the report is quoted below and followed by a discussion of the recommendation.

1. A broad policy objective be adopted for the entire Colorado River System which would result in salinity concentrations being maintained at or below levels presently found in the lower Colorado River.

It is suggested that this recommendation be made a part of Recommendation 5 and modified as will be discussed below.

> 2. Criteria for salinity concentrations be adopted by appropriate Colorado River Basin States in accordance with the Federal Water Pollution Control Act, as amended. As a minimum, these criteria should require that for any given month the average concentrations of total dissolved solids be maintained below 800 mg/l at Hoover Dam and 1,000 mg/l at Imperial Dam.

The Interstate Stream Commission does not concur in this recommendation and urges that it be deleted.

While the data given in the report do not so indicate, a review of the records reveals that the monthly average criterion of 1,000 mg/l at Imperial Dam as proposed was equaled in January of 1957 and has been closely approached a number of times in recent years. The monthly average criterion of 800 mg/l proposed for the Colorado River below Hoover Dam has been equaled or exceeded on many occasions, including some occurring in recent years.

Since virtually any beneficial consumptive use of water causes some increase in the concentration of dissolved solids in the remaining supply, the adoption of the proposed criteria would have the effect of precluding any new use of water above Hoover Dam, as well as some uses recently initiated. Some proposed new uses below Hoover Dam also would be precluded.

On January 30, 1968, then Secretary of the Interior Stuart Udall made the following remarks in a statement to the House Subcommittee on Irrigation and Reclamation (House Document 90-5, Colorado River Basin Project, Part II, pp. 705-706):

> "The Colorado River is the only major river of the world that is virtually completely controlled. With

the existing system of large storage reservoirs it is possible to plan, for all practical purposes, on complete utilization of the river's runoff with no utilizable water escaping to the sea. This means that the limited water supply in the Colorado River Basin must be used and reused and then used again for a wide variety of purposes. In this complete utilization of runoff, the Colorado Basin is unique.

The River is unique also with respect to the number and extent of the institutional constraints on the division and use of the Basin's water which include an international treaty, two interstate water compacts, Supreme Court decisions, Indian water rights, State water laws, and Federal law.

These two aspects, in turn, make the problem of setting numerical mineral quality standards for the Colorado River not only unique but extremely complicated. Before discussing this problem further, I would like to state that salinity standards will not be established until we have sufficient information to assure that such standards will be equitable, workable, and enforceable.

The principal water uses in the Basin include irrigated agriculture, municipal and industrial water supply, fish and aquatic life, and recreation. Salinity in the Colorado River has no significant effect on instream or nonconsumptive water uses such as hydroelectric power generation and water-oriented recreation. However, ever-increasing levels of salinity do have an adverse impact on the consumptive uses of water for both irrigated agriculture and municipal and industrial water supply.

Further development and depletion of water allocated to the Upper Basin States will raise the salinity of water downstream.

Salinity standards must be so framed that they will not impede the growing economy of the Colorado River Basin and yet not permit unwarranted degradation of

> water quality. This is the hard dilemma which is the core of the problem of establishing equitable salinity standards.
>
> A decision not to set salinity standards at this time does not and will not preclude getting started with programs to study and demonstrate the feasibility of controlling and alleviating the Basin's salinity problem...."

The adoption of the recommendation would be thoroughly inconsistent with the statement quoted.

The Colorado River compacts apportion among the seven states of the river basin the beneficial concumptive use of the waters of the Colorado River system. "Beneficial consumptive use" is defined as the amount of water diverted from the stream less the return flow thereto. This is a fair paraphrase of the definition used by the United States Supreme Court in its decision in Arizona v. California, et al.

When water is diverted from a stream for irrigation, for example, a part of the water is evaporated or taken up in the plants and the remainder returns to the stream. About two-thirds of the water applied to the land for the irrigation of crops is consumed by evaporation and moves off on the wind; the balance returns to the stream. That part of the water diverted that is consumed, or evaporated, is pure H_2O and that part which returns to the stream carries all of the dissolved minerals, or salinity, that was in the water diverted. This aspect of irrigation is also true for most other consumptive uses of water in the Basin. Some uses, particularly new irrigation projects and municipal use will necessarily, under any reasonable practice, return to the stream a tonnage of salt somewhat greater than the amount diverted. However, as the report reflects the preponderance of the projected increase in concentration of salts will result from the concentrating effect rather than from such additions of salt.

Thus, an inescapable consequence of the beneficial consumptive use of water is the degradation of water quality by an increase in the concentration of dissolved solids in the remaining water. Even though the tonnage of dissolved solids remains the same, the amount of water in which it is carried is less and the concentration is increased.

This simple principle of physics was as well known in 1922, when it was agreed to apportion 7½ million acre-feet of beneficial consumptive use to the Upper Basin, as it is today. Therefore, the Compact must be construed to contain an agreement that less water containing a greater concentration of dissolved solids will flow to the Lower Basin as the Upper Basin develops and uses the amount of water that it is entitled to.

The Colorado River Compact specifically provides for transmountain diversion of waters of the Colorado River System to which the state making such a diversion is entitled. Diversion of the relatively fresh headwaters of a stream to another basin will, of course, increase the concentration of dissolved solids in the supply remaining in the basin. This increase in concentration will not be as great as the increase that would result from the consumptive use of an equal amount within the basin.

Adoption and enforcement of the criteria proposed would preclude operation of the San Juan-Chama transmountain diversion project which will divert 110,000 acre-feet annually from the headwaters of the San Juan River into the Rio Grande Basin. The federal government has invested $57 million in the San Juan-Chama project to date; the project was put in operation this spring.

Operation of the 110,000 acre Navajo Indian Irrigation Project would also be precluded. The federal government has thus far invested $38 million in the construction of this project.

The principal function of the Navajo Dam and Reservoir Project is to store water for the Navajo Indian Irrigation Project and for municipal and industrial use. Operation of this project, which was completed in 1963 at a cost of $41.6 million, for those purposes would be precluded.

Construction of the Animas-La Plata Project in Colorado and New Mexico to furnish water for irrigation, municipal, industrial and recreation purposes was authorized in 1968. Operation of that project likewise would be precluded.

If the proposed criteria are adopted and enforced, New Mexico will be unable to make beneficial consumptive use of at least 500,000 acre-feet of the estimated 770,000 acre-feet that the state is entitled to under the Colorado River compacts. Similar, possibly even more severe effects, would be brought about in other states.

It might be argued that new uses of water such as those outlined above would be precluded only until the salinity control projects described in the report can be implemented. The feasibility, effectiveness and timing of those projects is, and may remain for some time, uncertain. It is not reasonable to propose that the upstream states terminate recently initiated water uses and defer activity for the development of new uses until salinity control projects such as those outlined in the report can be put into operation.

The report recognizes (page 48, second paragraph) that to maintain the concentration of dissolved solids in the Colorado River at present levels by limiting development in the Upper Basin would not be economic.

The adoption and enforcement of the proposed salinity criteria would effectively limit Upper Basin development and would be not only uneconomic, but also unrealistic and inequitable.

3. A State/Federal task group immediately be established to develop additional salinity control criteria at key points throughout the Basin which will accomplish the objectives of Recommendation 1. These criteria should be adopted on or before January 1, 1973 by the appropriate Colorado River Basin States in accordance with the Federal Water Pollution Control Act, as amended.

This recommendation should be deleted for the reasons set out in the discussion of Recommendation 2.

4. The possibility be explored of extending the authority of one or more existing agencies to assume the responsibility to plan, formulate policy, direct, and implement a comprehensive basinwide salinity control program. In the event existing authority is lacking or inappropriate, legislation should be sought to establish a permanent State/Federal agency or river basin commission which could assume such responsibility.

No extension of the authority of existing agencies or creation of new agencies or commissions is needed to "implement a comprehensive basinwide salinity control program". The U. S. Bureau of Reclamation's record of experience and achievement in the development and management of the Colorado River makes it the logical agency to assume the primary role in the program. The Bureau of Reclamation has been studying the salinity of the Colorado River under Congressional directive for a number of years.

Each of the states of the Colorado River Basin has recently urged committees of the Congress to appropriate money to the Bureau of Reclamation to carry out feasibility investigations of salinity control projects on the Colorado River.

Consultation and guidance from the Environmental Protection Agency should be valuable to the Bureau of Reclamation in its studies.

Recommendation 4 should be revised to support appropriations to the Bureau of Reclamation for feasibility investigations of salinity control projects.

5. Early measures be sought to authorize, fund and implement a basinwide salt load reduction program that would lead to achieving Recommendation 1.

The Interstate Stream Commission supports this recommendation and suggests that the necessary first step is the appropriation of funds to the Bureau of Reclamation for feasibility investigations. It is recommended that the Environmental Protection Agency contribute to the program by accelerating its ongoing research efforts and initiating new research projects that might contribute to conceiving or evaluating salinity control projects.

In consideration of the extensive federal land ownership and numerous federal water projects in the Basin, the international character of the Colorado River, the fact that salinity is a basinwide problem and the fact that salinity control beneficiaries will be very difficult to identify, it is recommended that the economic analyses of the feasibility investigations treat the construction, operation and maintenance cost of salinity control projects as an all-federal expense.

A number of the salinity control projects identified in the report, and other such projects that may be identified, will cause a depletion of streamflow. These depletions will occur in upstream states while the bulk of the benefits from the reduction in salinity will be realized in downstream states. This circumstance, because of the scarcity of water in the Colorado River System, will give rise to institutional problems. Such institutional problems are not seen as insurmountable and will be more readily resolved when all of the facts concerning a particular salinity alleviation project are available in the form of a feasibility report.

The thought of Recommendation 1 might better be made a part of Recommendation 5 with language added to recognize that it is almost inevitable that the concentration of dissolved solids in the Colorado River will increase somewhat above present levels before practicable salinity control measures can be put into effect.

There are several points at which the assumptions and economic analyses of the report are subject to question. We have foregone discussion of technical aspects of the report for the reason that we believe that the report adequately justifies the undertaking of feasibility investigations; that such investigations should and will be made; and that the technical aspects will be reviewed and modified as necessary in the course of those investigations.

The Interstate Stream Commission appreciates the opportunity given by the Environmental Protection Agency to review the report and your courtesy in forwarding these comments.

Sincerely,

S. E. Reynolds

/S. E. Reynolds
Secretary

SER:re

UTAH

CALVIN L. RAMPTON
Governor
RICHARD P. LINDSAY
Executive Director

STATE OF UTAH—DEPARTMENT OF SOCIAL SERVICES

DIVISION OF HEALTH
44 MEDICAL DRIVE
SALT LAKE CITY, UTAH 84113
AREA CODE 801
328-6121

Board of Health
Air Conservation Committee
Health Facilities Council
Medical Examiner Committee
Nursing Home Advisory Council
Water Pollution Committee

LYMAN J. OLSEN, M.D., M.P.H.
Director of Health

BUREAU OF ENVIRONMENTAL HEALTH
72 East 4th South
Salt Lake City, Utah

September 14, 1971

Mr. R. L. O'Connell
Acting Interim Regional Coordinator
Environmental Protection Agency
760 Market Street
San Francisco, California 94102

Dear Mr. O'Connell:

The following comments relate to our review of the draft report of "The Mineral Quality Problem in the Colorado River Basin".

We believe that the broad policy objective should be to maintain salinity levels in the Colorado River reasonably near or lower than existing levels, but that authorized use of Colorado River waters must proceed with acknowledgement of the possibility of some uncontrollable salinity increases, as is inevitable from any beneficial use.

Since there is not enough information presently available for accurate predictions as to achievable salinity levels, we oppose the idea of setting specific limits at this time. Instead, we support the concept of early measures to determine feasibility of a basinwide salt load reduction program. Implementation of such a program would improve our knowledge of the overall control situation and permit development of achievable and enforceable specific standards at a later date.

We do not believe it appropriate to seek creation of a new agency or task group to develop additional salinity control criteria at this time. It seems logical that the present group of conferees, working in harmony with the Water Quality Office, can more effectively accomplish what is needed.

I question the advisability of an early re-convening of the Conferees since they appear to be in general agreement with the above comments.

Sincerely yours,

Lynn M. Thatcher
Deputy Director of Health
and
Conferee on Pollution of the Interstate Waters
of the Colorado River and its Tributaries

LMT:cc

cc: State Division of Water Resources
Dallin Jensen, Asst. Attorney General

WYOMING

THE STATE OF WYOMING

Department of Health and Social Services

Division of Health and Medical Services

STATE OFFICE BUILDING CHEYENNE, WYOMING 82001

June 1, 1971

Mr. R. L. O'Connell
Acting Interim Regional Coordinator
Environmental Protection Agency
760 Market Street
San Francisco, California 94102

Dear Mr. O'Connell:

The draft reports on the Mineral Quality Problem in the Colorado River Basin have been reviewed by several state agencies. At this point in time, we feel it is not necessary to argue methodology or economic theory. Certainly competent personnel has been involved from the start. It is obvious that certain assumptions had to be made in conducting the study, and while we may not agree with all of these assumptions, the need for making them and the competence of the people involved in the study is unquestioned.

In the final analysis of this problem, it is realized that a general approach was necessary. Item 9 c. in the summary of the findings could be a valid alternate in a generalized approach. However, it has to be acknowledged at the start of any action program that such a limitation would not be acceptable to the State of Wyoming and probably other Basin States with undeveloped water resources. It must be firmly understood, at the start, that water quality standards will not be a means of circumventing the Colorado River Compact on water allocation.

Under Recommendations, Item 4 may be questionable, depending upon the powers granted. Certainly the State of Wyoming would not relinquish their authority concerning how and where water might be utilized within the State.

Attached are comments that are being submitted by the State Engineer's office.

Very truly yours,

Arthur E. Williamson

Arthur E. Williamson, M.S., P.E.
Director
Sanitary Engineering Services

AEW:cw
Attachment

cc: Floyd Bishop, State Engineer, Cheyenne

THE STATE OF WYOMING

State Engineer's Office

STATE OFFICE BUILDING CHEYENNE, WYOMING 82001

June 1, 1971

MEMORANDUM

TO: Interim Regional Coordinator,
Environmental Protection Agency
Region IX
760 Market Street
San Francisco, California 94102

FROM: Floyd A. Bishop,
Wyoming State Engineer

THROUGH: Arthur Williamson, Conferee
Joint Federal-State "conference in the matter of Pollution of the Interstate Waters of the Colorado River and its Tributaries."

SUBJECT: Comments on the report entitled Mineral Quality Problems in the Colorado River Basin, dated November, 1970.

Dear Sir:

We have carefully reviewed the draft report on the Mineral Quality Problems in the Colorado River Basin, and our comments on that report are submitted herewith.

Throughout the report there are numerous statements to the effect that one of the alternatives for accomplishing a reduction of future salinity concentrations was limiting further use of water in certain areas of the river basin. This approach would be patently unfair to those states that are not yet using their full Colorado River Compact allocations, primarily the Upper Basin states.

The Upper Basin states ratified the Colorado River Compact permitting the Lower Basin states to develop under the assumption that the Upper Basin states were also entitled to develop at their own rate and use their allocation of water, thereby reducing the flow to the Lower Basin. In addition, since Upper Basin development has not been as rapid as that of the Lower Basin, the Lower Basin has been able to use a water supply which is better in both quantity and quality that it is ultimately entitled to. Therefore, it would be extremely inequitable to inhibit federal assistance to, or limit in any way, the continued development of, the Upper Colorado River Basin. It would in fact, be a circumvention of the provisions of the treaties and compacts which make up the "Law of the River."

The most equitable solution to the salinity problem is a basin-wide salinity reduction program, with its costs assigned to the beneficiaries of the improved quality water. This would hold true regardless of the physical location of the individual salinity control projects, or whether they be structures to improve irrigation efficiency or ponds to evaporate saline springs. Admittedly, the task of identifying all the beneficiaries of improved water quality would be a formidable one. The costs assigned to those beneficiaries who could not be readily identified should be absorbed by the Federal Government. The Federal Government has an inherent interest and responsibility, since it owns 70% of the lands within the Basin, and would be a prime beneficiary.

The report assigned one-half of the costs of irrigation improvement projects to salinity control and one-half to the irrigators benefited directly by such improvements. Perhaps this estimate of 50% is not an overstatement where irrigators suffer from water shortages and drainage problems as they generally do in the Lower Main Stem and the Southern California regions. But in areas where neither of these problems are serious, the probable benefits to a farmer from an improvement in his irrigation efficiency are less significant.

The report recommended that a State/Federal agency should carry on feasibility studies and otherwise administer basin-wide salinity control programs. We agree with that proposal and further suggest that the Bureau of Reclamation be given initial responsibility for carrying out the studies with close cooperation from the Basin States. We agree that the planning phase should be directed toward the objectives of providing sufficient information for developing an implementation plan, of providing the feasibility reports on which requests for construction funds for necessary control works can be based, and of identifying construction, operation and related costs which would be properly assigned to the beneficiaries and to other entities.

We appreciate the opportunity of commenting on the draft reports on the Mineral Quality Program in the Colorado River Basin. Your courtesy in extending the time for submitting comments to June 7 has been helpful.

This matter is of great significance to all of the states of the Colorado River Basin. We are anxious to be involved in the activities which may stem from this report and hereby request that you continue to keep us informed of progress made and actions taken on this subject.

FAB/TB/mt

cc: Governor Stanley K. Hathaway
A. E. Williamson

OTHER AGENCIES

UPPER COLORADO RIVER COMMISSION
355 South Fourth East Street
Salt Lake City, Utah 84111

July 2, 1971

Hon. William D. Ruckelshaus
Administrator
Environmental Protection Agency
1626 K Street
Washington, D. C. 20460

Dear Mr. Ruckelshaus:

In April, 1971 the Environmental Protection Agency transmitted for review by the seven Colorado River Basin States and other interested entities a draft summary report (with three appendices) entitled "The Mineral Quality Problem In The Colorado River Basin." This report was prepared by the Federal Water Quality Administration.

Enclosed is a copy of a resolution adopted by the Upper Colorado River Commission at its Adjourned Regular Meeting held in Denver, Colorado on June 30, 1971. This resolution expresses the basic elements of the position of the Commission's four member States on the mineral quality report.

The Upper Colorado River Commission is an administrative agency created by the Upper Colorado River Basin Compact. The Commission represents the States of Colorado, New Mexico, Utah, and Wyoming in matters pertaining to the development, utilization, and conservation of the waters of the Upper Colorado River Basin.

Sincerely yours,

Ival V Goslin

Ival V. Goslin
Executive Director

IVG:hiw
Enclosure

CERTIFICATE

I, IVAL V. GOSLIN, Executive Director of the Upper Colorado River Commission, do hereby certify that the above Resolution was unanimously adopted by the Upper Colorado River Commission at an Adjourned Regular Meeting held at Denver, Colorado on June 30, 1971.

WITNESS my hand this 2nd day of July, 1971.

Ival V Goslin

Ival V. Goslin
Executive Director

Resolution

by

Upper Colorado River Commission

re:

Draft Report Entitled, The Mineral Quality Problem In The Colorado River Basin by Federal Water Quality Administration

June 30, 1971

WHEREAS, on August 8, 1962, the Upper Colorado River Commission unanimously adopted a resolution favoring "a study of any and all measures for the reduction of the salinity of Colorado River waters delivered for use in the Republic of Mexico"; and

WHEREAS, on September 21, 1967, said Commission, after having been informed that the Federal Water Pollution Control Administration had proposed that quantitative criteria for total dissolved solids be set at various points in the Colorado River system based on an upper limit of 1000 mg/l at Imperial Dam, unanimously adopted another resolution stating that: "water quality criteria on the Colorado River should not preclude or interfere with the reasonable use of water in the Upper Basin within the terms of the Colorado River Compact"; and

WHEREAS, in April 1971, the Environmental Protection Agency transmitted to the States of the Colorado River Basin a preliminary draft of Summary Report on "The Mineral Quality Problem In The Colorado River Basin" prepared under the jurisdiction of the Federal Water Quality Administration of the Department of the Interior, and requested comments thereon; and

WHEREAS, said Summary Report constitutes only a reconnaissance step toward the solution of the mineral quality problem of the Colorado River system, and lacks sufficient information to assure that numerical salinity control standards would be equitable, workable, and enforceable; and

WHEREAS, said Summary Report contains certain recommendations including a recommendation that numerical salinity criteria of 1000 mg/l monthly average at Imperial Dam and 800 mg/l monthly average at Hoover Dam be implemented at this time. This recommendation is diametrically opposed to previously stated policies of the Upper Colorado River Commission and the major purpose of the Upper Colorado River Basin Compact "to secure the expeditious agricultural and industrial development of the Upper Basin, . . . ":

NOW, THEREFORE, BE IT RESOLVED by the Upper Colorado River Commission that:

(1) any broad policy objective pertaining to salinity control for the entire Colorado River System must treat the salinity problem as a basinwide problem that needs to be solved to maintain Lower Basin water quality reasonably near present levels while the Upper Basin continues to develop its compact-apportioned water and must recognize that water quality may be degraded until control measures become operable;

(2) numerical salinity control criteria should not be established until salt load reduction projects have been constructed and their operation proved practicable;

(3) the consumptive use of water in salinity control projects must be charged to the beneficiaries of those salinity control projects;

(4) the Bureau of Reclamation should be assigned the primary responsibility for feasibility investigations, planning, and implementing a basinwide salt load reduction program at Federal expense in recognition of the major responsibilities of the United States with respect to the Colorado River as an interstate and international stream; and

(5) the member States of the Upper Colorado River Commission should cooperate with the three lower Colorado River Basin States and the Federal government in the resolution of the mineral quality problem of the Colorado River System.

BE IT FURTHER RESOLVED that the Environmental Protection Agency be commended for making available copies of the Summary Report on "The Mineral Quality Problem In The Colorado River Basin" for review by interested agencies of the seven Colorado River Basin States; and

BE IT FURTHER RESOLVED that copies of this resolution be transmitted to the Administrator of the Environmental Protection Agency, Secretary of the Interior, Governors and Members of the Congress of the Colorado River Basin States, Commissioner of Reclamation, and other interested entities.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1972 722-874/461